ARC WELDING

in

DESIGN, MANUFACTURE *and* CONSTRUCTION

THE James F. Lincoln ARC WELDING FOUNDATION

PRICE $1.50 IN U. S. A.
$2.00 ELSEWHERE
Postage Prepaid

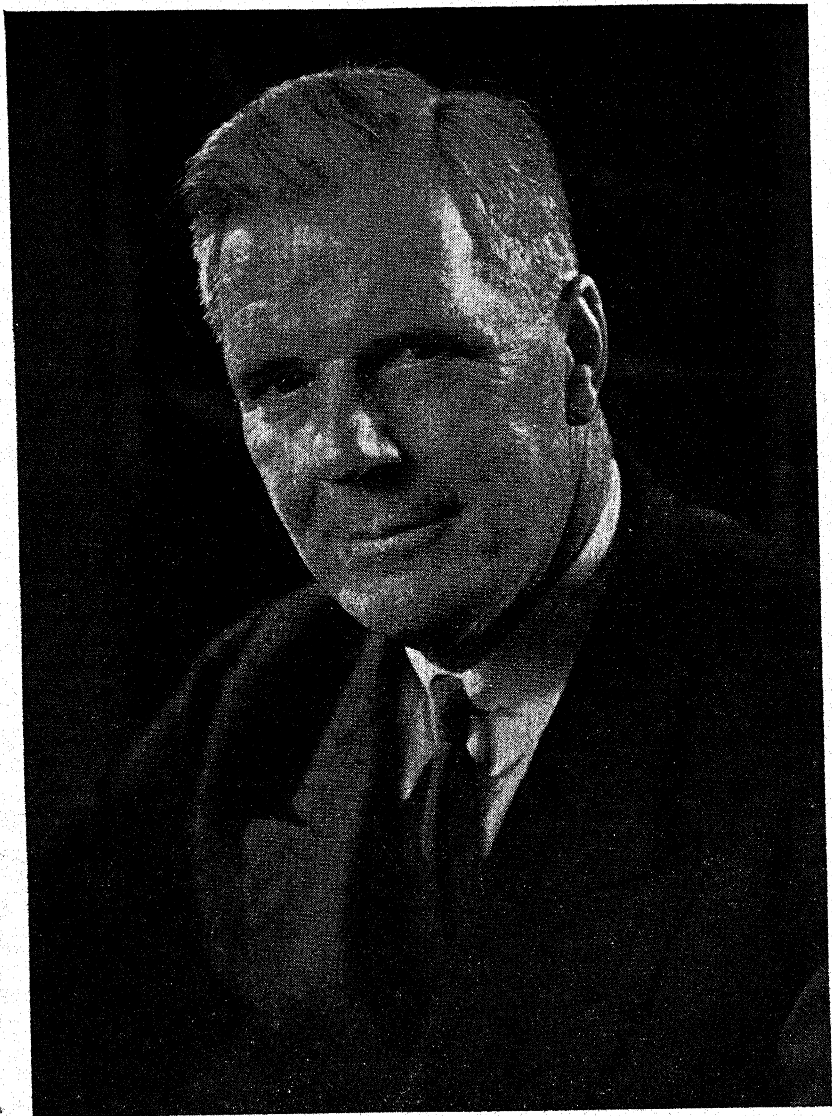
This book may be ordered through any recognized book dealer or direct from
THE JAMES F. LINCOLN ARC WELDING FOUNDATION
CLEVELAND, ... OHIO

Published by
THE JAMES F. LINCOLN ARC WELDING FOUNDATION

First Printing, March, 1939
Second Printing, July, 1939
Third Printing, August, 1940
Fourth Printing, March, 1942
Fifth Printing, September, 1942
Sixth Printing, March, 1943
Seventh Printing, March, 1944
Eighth Printing, July, 1944
Ninth Printing, April, 1945

Printed in U. S. A.

This book is dedicated
to scientific progress
of arc welding



J. F. Lincoln, president of the Lincoln Electric Co., Cleveland, Ohio, and pioneer in arc welding development, in whose honor The James F. Lincoln Arc Welding Foundation was created.

Why The James F. Lincoln Arc Welding Foundation Was Created—

Regarding the creation of The James F. Lincoln Arc Welding Foundation, Mr. J. C. Lincoln, chairman of the board of directors of The Lincoln Electric Co., the founder, made the following statement which is quoted from the original deed of trust.

"Since the dawn of recorded time, man has struggled constantly to improve his conditions. Coping with many obstacles, he has developed great skill and ingenuity. Applied through the years, these talents have rewarded man with luxuries of which his ancestors never dreamed—the telephone, the radio, the automobile, the airplane, the railroad, the steamship, the skyscraper, the gigantic bridge—these modern wonders and many others are the products of man's skill and ingenuity.

"Recent years have seen the origin and development of an ingenious process which has great economic, social and commercial significance to mankind. That process is arc welding.

"It is, therefore, our belief that by encouraging and stimulating scientific interest in and study of arc welding, still greater benefits will result from man's skill and ingenuity. To this end, The Lincoln Electric Co. announces that it has created, in honor of its president, 'The James F. Lincoln Arc Welding Foundation,' which is to sponsor an Arc Welding Award Program offering rewards totaling $200,000."

The Lincoln Electric Company
J. C. Lincoln, Chairman of the Board of Directors

Object and Purpose of The James F. Lincoln Arc Welding Foundation

"The object and purpose of The James F. Lincoln Arc Welding Foundation is to encourage and stimulate scientific interest in, and scientific study, research and education in respect of, the development of the arc welding industry through advance in the knowledge of design and practical application of the arc welding process, and to provide for the payment of awards, by prizes, to those persons who by reason of the excellence of their papers upon said subject may be selected in the manner herein provided as most worthy to receive such awards."

The $200,000 Award Program -- First Activity of Foundation to Stimulate Progress of Arc Welding

The first activity of The James F. Lincoln Arc Welding Foundation to encourage scientific progress of arc welding was the $200,000 Award Program, which was announced in February 1937 and closed June 1st, 1938. The awards were made on September 15th, 1938.

Program Offered 446 Awards.—The following is quoted from the Rules and Conditions governing participation in the Award Program:—

"A total of 446 awards are provided for papers in this program. From the 44 sub-classifications, 220 papers will be selected to receive awards totaling $81,400.

"From the 220 papers receiving awards in the sub-classification, 44 papers will be selected to receive awards totaling $74,800 in the main classifications.

"From the 44 papers receiving awards in the main classifications, papers will be selected to receive the four main program awards totaling $26,000.

"Additional awards—178 awards of $100 each are provided for papers which do not share in any other award but which in the opinion of the Jury of Award deserve Honorable Mention. These may be selected from any classification.

"The winner of the Grand Award for the program will receive $13,700. He will receive the first award of $10,000 for the program, the first award of $3,000 for his main classification and the first award of $700 for his sub-classification."

Industrial Classifications and Subject Divisions of the $200,000 Award Program

The Award Program was divided into 11 industrial classifications covering 44 subject divisions as given below:

Industrial Classification	Subject Divisions
A AUTOMOTIVE	A-1 Engines A-2 Bodies A-3 Frames A-4 Trailers
B AIRCRAFT	B-1 Engines B-2 Fuselages
C RAILROAD	C-1 Locomotives C-2 Freight Cars C-3 Passenger Cars C-4 Locomotive and Car Parts
D WATERCRAFT	D-1 Commercial D-2 Pleasure
E STRUCTURAL	E-1 Buildings and Similar Structures E-2 Bridges E-3 Houses E-4 Miscellaneous
F FURNITURE and FIXTURES	F-1 House F-2 Office
G COMMERCIAL WELDING	G-1 Commercial Welders or Job Shops G-2 Garages or Service Stations
H CONTAINERS	H-1 Contents Stationary (tanks, etc.) H-2 Contents Moving (pipe lines, etc.)
I WELDERIES	I-1 Commercial Welderies I-2 Plant Welderies
J FUNCTIONAL MACHINERY	J-1 Metal Cutting J-2 Metal Forming J-3 Electrical J-4 Prime Movers J-5 Conveying J-6 Pumps and Compressors J-7 Business J-8 Functional Machinery not otherwise classified J-9 Jigs and Fixtures J-10 Parts of Functional Machinery
K INDUSTRY MACHINERY	K-1 Processing K-2 Construction K-3 Petroleum K-4 Steel Making K-5 Farming K-6 Household K-7 Food Making K-8 Textile and Clothing K-9 Printing K-10 Industry Machinery not otherwise classified

Subject Matter of Papers in the $200,000 Award Program

The following definitions of subject matter for papers in the Award Program are quoted from the Rules and Conditions of the Foundation governing participation.

"Participation in this Program necessitates submission of a paper which shall describe one of the following:

"(a) Redesign of existing machine, structure, building, etc. A machine structure, building, manufactured or fabricated product of ferrous or non-ferrous metals within the limits hereinafter prescribed, previously made in some other way, which has been redesigned in whole or in part, so that arc welding may be applied to its manufacture.

"(b) New design of machine, structure, building, etc., not previously made. A machine, structure, building, manufactured or fabricated product of ferrous or non-ferrous metals within the limits hereinafter prescribed, not previously made but which has been designed in whole or in part for the use of arc welding, the description to show how a useful result, which was impractical with other methods of construction, or could be better done by arc welding, is obtained. To qualify, the machine, structure, building, manufactured or fabricated product so designed need not have been manufactured or built at the time of the writing of the paper.

"(c) Organizing, developing and conducting a welding service to be described in the papers may be conducted by Commercial Welders or Job Shops (G-1), Garages or Service Stations (G-2), Commercial Welderies (I-1) or Plant Welderies (I-2).

"Note that the machine, structure, building, manufactured or fabricated product under (a) or (b) may be designed either in whole or in part for the use of arc welding. However, preference will be given to papers describing products showing fullest use of arc welding."

Submission of Papers.—In submitting papers for the Award Program, contestants were asked to observe certain requirements which are quoted from the official Rules and Conditions:

"Papers must be submitted in duplicate, one signed by the contestant and enclosed in a separate, sealed envelope with the following information clearly written on the cover sheet of the paper and on the outside of such sealed envelope:

Name, address and signature of the contestant;

Name of concern building the product described in the paper;

Relation between the contestant and the concern building the product;

The classification for which the paper is entered.

"The contestant at the same time shall enclose in another envelope a duplicate of such paper, which shall not be signed, but it shall have on it and on the envelope in which it is to be placed, only a statement of the classification for which the contestant enters the paper.

"When received by the secretary, the envelope in which both papers are enclosed will be opened by the secretary of the foundation and immediately the same identifying number will be given to the envelope containing the signed paper and the envelope containing the duplicate unsigned paper. The envelope containing the signed paper will be retained, unopened and confidential. The envelope containing the duplicate paper, with the number identifying the contestant and the endorsement of the contestant of the classification for which the paper is entered, will be delivered, unopened, to the Jury of Award, with other contesting papers, at the close of the program.

"The object will be to treat all papers confidential, without disclosure, until the Jury of Award considers the identified but unsigned contesting papers. When the award papers are selected by the Jury of Award, proper certificate thereof will be made upon the number of the paper so submitted, and then identified with the original paper on file with the secretary, and payments thus made to the winners by the Foundation."

Recording and Handling of Papers.—As the papers were received in Cleveland by the Foundation, the same identifying number was given to the envelope containing the signed paper and the envelope containing the duplicate unsigned paper. A card was made out recording the author's name, address, classification of his paper, as well as the number assigned to the paper. At the same time, another record was made of the paper numerically, giving the author's name, his address, his employer, and the classification of his paper. In addition, the paper was recorded according to its classification on sheets prepared especially for this purpose.

Only papers contained in envelopes postmarked not later than June 1st, 1938, and received in Cleveland not later than July 1st, 1938, were accepted. The total of 1981 papers were found acceptable under the rules.

By letter of July 29th, 1938, the Jury of Award of The James F. Lincoln Arc Welding Foundation certified to the secretary its decisions concerning papers submitted in the Award Program. The certification of papers was by number, in accordance with the Rules of Awards.

Upon receipt of the Jury's report, the Secretary and Assistant Secretary of the Foundation, identified the authors of the award-winning papers by reference to the various records.

Jury of Award

CHAIRMAN

DREESE, E. E., Head of Department of Electrical Engineering, Ohio State University

JURORS

BENEDICT, R. R., *Assistant Professor of Electrical Engineering,* University of Wisconsin

BOONE, E. M. *Assistant Professor of Electrical Engineering,* Ohio State University

BURCKMYER, L. A., *Associate Professor of Electrical Engineering,* Cornell University

CALDWELL, F. C., *Professor of Electrical Engineering,* Ohio State University

CHAMBERLAIN, R. F., *Professor of Electrical Engineering,* Cornell University

CONLON, E. W., *Assistant Professor of Aeronautical Engineering,* University of Michigan

EVERITT, W. L., *Professor of Electrical Engineering,* Ohio State University

GROVER, LAMOTTE, *Assistant Professor of Mechanics Department,* Kansas State College

HALL, R. A., *Professor of Division of Engineering,* Union College

HIBSHAM, N. S., *Associate Professor of Electrical Engineering,* Lehigh University

JONES, E. W., *Instructor of Electrical Engineering,* Cornell University

KUNZE, A. A., *Instructor of Electrical Engineering,* Ohio State University

KYLE, P. E., *Assistant Professor of Mechanical Engineering,* Massachusetts Institute of Technology

LEHOCZKY, PAUL, *Assistant Professor of Industrial Engineering,* Ohio State University

LUCE, A. W., *Associate Professor of Mechanical Engineering,* Lehigh University

MAHANEY, J. P., *Assistant Professor of Industrial Engineering,* Virginia Polytechnic Institute

MANNING, E. W., *Instructor of Electrical Engineering,* Cornell University

MARQUIS, F. W., *Professor, Head of Mechanical Engineering Department,* Ohio State University

MCKEE, W. S., *Assistant Professor of Mechanical Engineering,* Carnegie Institute of Technology

MICKLE, F. A., *Associate Professor of Mechanical Engineering,* University of Michigan

MORRIS, CLYDE T., *Professor, Head of Civil Engineering Department,* Ohio State University

NORTHROP, M. G., *Assistant Professor of Electrical Engineering,* Cornell University

O'ROURKE, C. E., *Professor of Civil Engineering,* Cornell University

OTT, P. W., *Professor, Head of Mechanics Department,* Ohio State University

ROTHROCK, H. H., *Professor of Industrial Engineering,* University of Pittsburgh

RUTTER, M. L., *Instructor of Civil Engineering,* University of Pittsburgh

TAYLOR, JACOB, *Professor, Head of Accounting Department,* Ohio State University

WILBUR, J. B., *Associate Professor of Civil Engineering,* Massachusetts Institute of Technology

WILLIAMS, J. E., *Instructor of Electrical Engineering,* Ohio State University

YOUNGER, JOHN, *Professor, Head of Industrial Engineering Department,* Ohio State University

In addition to the above jurors, experts or outstanding authorities in the various classifications covered by the Program were consulted in order to properly appraise the merits of the papers.

Certification of Papers for Award

The following is a copy of the Jury of Award's certification announcing the numbers of the papers selected to receive awards:

First Grand Award — Paper No. 1132—
"Commercial Weldery;"

Second Grand Award — Paper No. 1969 —
"The All-Welded Grid Applied to Plane and Spatial Structures;"

Third Grand Award — Paper No. 836 —
"Industrial Machinery: Steel Making;"

Fourth Grand Award — Paper No. 710 —
"Arc Welding in Aircraft Heating."

Of the Class A Awards, the following awards are made:

1st	2nd	3rd	4th
1670	1783	1628	1480

Of the A sub-class Awards, the following awards are made:

	1st	2nd	3rd	4th	5th
A-1	1977	369	469	921	309
A-2	1670	1783	809	1831	1586
A-3	1628	1148	380	859	671
A-4	1480	669	1431	559	832

and Honorable Mention Awards as follows:

A-1	None
A-2	436
A-3	358
	1784
A-4	953
	1961

Of the Class B Awards, the following awards are made:

1st	2nd	3rd	4th
710	1867	1372	1049

Of the B sub-class Awards, the following awards are made:

	1st	2nd	3rd	4th	5th
B-1	1153	792	Vacate	Vacate	Vacate
B-2	710	1867	1372	1049	1819

and Honorable Mention to the following:

B-1	None
B-2	171
	861

Of the Class C Awards, the following awards are made:

1st	2nd	3rd	4th
1952	1346	1333	972

Of the C sub-class Awards, the following awards are made:

	1st	2nd	3rd	4th	5th
C-1	1952	1346	1333	249	Vacate
C-2	972	1584	668	1924	1472
C-3	595	1951	Vacate	Vacate	Vacate
C-4	1309	602	401	244	179

and Honorable Mention to the following:

C-1	None
C-2	None
C-3	None
C-4	1758

Of the Class D Awards, the following awards are made:

1st	2nd	3rd	4th
1911	898	554	365

Of the D sub-class Awards, the following awards are made:

	1st	2nd	3rd	4th	5th
D-1	1911	898	554	365	811
D-2	1409	1141	1519	438	501

and Honorable Mention to the following:

D-1	174	864	1085	1590
	723	1012	1135	1960
	788	1026	1512	1974
D-2	769			
	979			
	1842			

Of the Class E Awards, the following awards are made:

1st	2nd	3rd	4th
1969	442	349	1109

Of the E sub-class Awards, the following awards are made:

	1st	2nd	3rd	4th	5th
E-1	1969	1319	1086	1885	682
E-2	1109	287	1127	1697	1080
E-3	1711	752	385	1557	1151
E-4	442	349	1878	1177	505

and Honorable Mention to the following:

E-1	226	549	1883	1025	1915	662	522	693
	557	672	1618					
E-2	1731	368	1278	931	1123	1853	664	699
	1865	1706	1750	1753	655	730		
E-3	None							
E-4	1465	623	1254	1341	1250	1236	480	1029
	31	1152	1895	143	1464	1551	32	

Of the Class F Awards, the following awards are made:

1st	2nd	3rd	4th
528	1230	474	1414

Of the F sub-class Awards, the following awards are made:

	1st	2nd	3rd	4th	5th
F-1	474	1656	1833	1863	276
F-2	528	1230	1414	1799	151

and Honorable Mention to the following:

F-1 None
F-2 None

Of the Class G Awards, the following awards are made:

1st	2nd	3rd	4th
273	673	1794	1059

Of the G sub-class Awards, the following awards are made:

	1st	2nd	3rd	4th	5th
G-1	273	673	1794	23	1873
G-2	1059	630	1038	Vacate	Vacate

and Honorable Mention to the following:

G-1 88 1691 1303 1042 1539 1533 1497 591 1701 144 646 696
G-2 None

Of the Class H Awards, the following awards are made:

1st	2nd	3rd	4th
1560	597	540	1874

Of the H sub-class Awards, the following awards are made:

	1st	2nd	3rd	4th	5th
H-1	540	1874	497	1941	1598
H-2	1560	597	1385	149	881

and Honorable Mention to the following:

H-1 851 590 973 1601 666 842 1357 1185 490 479
H-2 1344 1306 1594 1722 1403 1000 915 1424 30 1150

Of the Class I Awards, the following awards are made:

1st	2nd	3rd	4th
1132	687	758	552

Of the I sub-class Awards, the following awards are made:

	1st	2nd	3rd	4th	5th
I-1	1132	758	1468	1572	281
I-2	687	552	1522	1532	1530

and Honorable Mention to the following:

I-1 None
I-2 1571 637 1968 312 495 78 367 1877 1172 692 539 359

Of the Class J Awards, the following awards are made:

1st	2nd	3rd	4th
1032	800	519	1332

Of the J sub-class Awards, the following awards are made:

	1st	2nd	3rd	4th	5th
J-1	1862	1587	1861	928	727
J-2	1871	1065	498	1714	1415
J-3	1032	1868	1517	750	Vacate
J-4	800	519	694	1824	302
J-5	1332	1884	440	366	987
J-6	978	1808	1027	1599	1528

	1st	2nd	3rd	4th	5th
J-7	1187	Vacate	Vacate	Vacate	Vacate
J-8	1371	1147	1975	1199	930
J-9	1248	611	622	849	844
J-10	198	456	1498	1384	926

and Honorable Mention to the following:

J-1	1546	1575	805					
J-2	1191							
J-3	None							
J-4	None							
J-5	1210	855	609	1520	927	15	624	1355
	1843	1459	1136					
J-6	618							
J-7	None							
J-8	231	686	1452	736	1218	1515	991	1927
	67	576	1757	1240	1186	965	1882	
J-9	1103	1592	223	104	822			
J-10	678	521	954	875	1419			

Of the Class K Awards, the following awards are made:

1st	2nd	3rd	4th
836	1345	1340	1057

Of the K sub-class Awards, the following awards are made:

	1st	2nd	3rd	4th	5th
K-1	1793	741	1531	1395	1423
K-2	1163	1647	1129	1096	1330
K-3	1537	1724	1547	326	1693
K-4	836	347	1114	1095	778
K-5	491	1649	1031	239	413
K-6	1524	1293	545	1580	824
K-7	1110	1076	1804	878	774
K-8	1057	1611	1227	1585	63
K-9	259	221	899	Vacate	Vacate
K-10	1345	1340	242	555	607

and Honorable Mention to the following:

K-1	1170	1338	1245	245	1617	933	685	175
	435	463	518	502	1516	1286		
K-2	1566							
K-3	1104	1827	1615	1138	884			
K-4	322	1261	1553					
K-5	1849	1775						
K-6	None							
K-7	701	1754						
K-8	None							
K-9	None							
K-10	247	801	465	1582				

Adjustment of Awards as Required by the Rules and Conditions

From the certification printed in the foregoing pages, it will be noted that 16 awards were vacated by the Jury in judging the papers. The amount of vacated awards was $3450. As required by the Rules and Conditions, in the following quoted paragraph, the vacated amount was distributed proportionately to those receiving awards:

"If, in the opinion of the Jury of Award, papers of sufficient merit to warrant the award of prizes are not presented in one or more classifications, the unawarded prizes will be distributed proportionately amongst all the winning contestants. For example, if $10,000 of the prize money is unawarded in any classification or classifications, this $10,000 will be spread over the $190,000 of awarded prizes by increasing each and every awarded prize by 1/19 of the amount originally allocated to it. Thus the Grand Award of $13,700 would be increased by $721.05, to $14,421.05, and a sub-group prize of $300 would be increased to $315.79."

Under the above provision, the $3450 of vacated awards was distributed proportionately amongst all the winning contestants, thus making the awards somewhat larger than originally provided.

Preface

The trustees of The James F. Lincoln Arc Welding Foundation, feeling that the papers submitted in the Award Program constitute a large and valuable source of scientific study, research and information, resolved to make the material generally available. The trustees, consequently, authorized publication of the most outstanding papers in book form. The result is this volume, *Arc Welding in Design, Manufacture and Construction.*

The object in editing *Arc Welding in Design, Manufacture and Construction* was to produce an accumulation of data of maximum originality, variety and usefulness.

109 award papers comprise the book. They were selected so that the entire compilation would afford the widest possible variety of subject matter.

The great majority of the papers are printed in full. Those which were too lengthy to be reproduced in their entirety, are included as comprehensive briefs. In briefing any paper, only such material was deleted or condensed which, it was felt, could be so treated without depreciating the value of the study. This same consideration pertained to illustrations. Only such drawings, photographs, charts, tables, etc., were omitted which were considered not absolutely vital to a clear and understandable presentation of the authors' subjects.

Arc Welding in Design, Manufacture and Construction is a compilation of comprehensive studies by men who are acknowledged leaders in their fields. These men—engineers, designers, architects, draftsmen, production officials and others—by applying their abilities to the particular study called for in the Award Program, discovered new benefits to be obtained through arc welding. The results of their studies, set forth in this volume, should prove an invaluable contribution to industrial progress.

Knowing the earnestness with which the authors of papers in the Award Program approached their subjects, the thoroughness and exactness with which they carried out their studies, the long hours spent in accumulating and arranging their data and the highly scientific treatment and handling of the many details in connection with preparing their papers, The James F. Lincoln Arc Welding Foundation herewith acknowledges the value and benefit of the authors' labors to not only the arc welding industry but to industry and society as a whole.

—THE EDITORS

Alphabetical List of Authors

Anderson, John N., Design Engineer, Otis Elevator Co., New York, N. Y. Award: $1,526.33. Title of paper: "A Welded Elevator Machine." See Section IX, page 1063.

Ashton, Ned L., Designer, Ash, Howard, Needles & Tammen, Kansas City, Mo. Award: $101.75. Title of paper: "Arc Welded Steel Plate Floors Applied to Bridges and Viaducts." See Section V, page 543.

Atwood, Gilbert H., Assistant Chief Draftsman, Dravo Corp., Pittsburgh, Pa. Award: $305.26. Title of paper: "A Welded Industrial Building." See Section V, page 473.

Bailey, Milo, President and Chief Engineer, The Bailey Steel Shipbuilding Co., Detroit, Mich. Award: $712.28. Title of paper: "Arc Welded Steel Pleasure Cruisers." See Section IV, page 377.

Baxter, John M., Chief Mechanical Engineer, Sir William Arrol & Co., Ltd., Glasgow, S.E., Scotland. Award: $712.28. Title of paper: "Welded Riveting Machine." See Section IX, page 996.

Beach, Fred S., Sr., Designing Engineer, New Haven Carriage and Auto Works, Portland, Oregon. Award: $2,543.88. Title of paper: "Sheet Steel Line Truck Body Fabricated by Arc Welding." See Section I, page 16.

Beensen, Charles, Mechanical Engineer and Designer, Cocoa, Fla. Award: $712.28. Title of paper: "Design of Propeller Type Pump for Arc Welded Construction." See Section IX, page 1113.

Bergmann, R. F., Chief Engineer, Rayon Machinery Corp., Cleveland, Ohio, co-author with A. F. MacDonald. Award: $1,526.33. Title of paper: "Welded Steel Supporting Structures for Continuous Process Rayon Producing Machines." See Section IX, page 1246.

Bickford, Harold D., Chief Engineer, Lombard Traction Engine Co., Waterville, Maine. Award: $101.75. Title of paper: "Saving Made by Arc Welding in Tractor Construction." See Section I, page 73.

Birkmeyer, Paul J., 60 Hudson St., New York, N. Y. Award: $2,543.88. Title of paper: "A Modern All-Purpose Steel Table Designed for Arc Welding." See Section VI, page 672.

Bishop, J. O., Master Mechanic, The National Supply Co., Torrance, Calif. Award: $2,747.39. Title of paper: "An Arc Welded Manipulator." See Section IX, page 1279.

Bjorkman, A. W., Manufacturing Supervisor, Otis Elevator Co., Yonkers, N. Y. Award: $203.51. Title of paper: "A Welding Fixture for Welding Bedplates." See Section X, page 1361.

Boath, Howard E., Senior Engineer, Corps of Engineers, U. S. Army, St. Louis, Mo., co-author with Charles F. MacNish. Award: $1,526.33. Title of paper: "Design of an Arc Welded Elliptical Tainter Gate." See Section V, page 627.

Bolin, Clinton, Draftsman, Lloyd Mfg. Co., Menominee, Mich. Award: $1,729.84. Title of paper: "More Advanced Design and More Rigid Construction of Chromium Tubular Furniture." See Section VI, page 676.

Boyer, Fred A., Mechanical Inspector, A. T. & S. F. Ry., Topeka, Kansas, co-author with Edgar Brooker. Award: $508.77. Title of paper: "Arc Welded Steel Roof for Freight Cars." See Section III, page 243.

Bratfisch, Alfred Ernest, Hydraulic Engineer, City of Los Angeles, Department of Water & Power, Los Angeles, Calif. Award: $203.51. Title of paper: "Design of an Arc Welded Penstock of Nickel Clad Steel." See Section VIII, page 886.

Brooker, Edgar, Metallurgist, U. S. Navy, Bureau of Construction and Repair, Arlington, Va. Co-author with Fred A. Boyer; see above.

Bulaw, Adolph, Vice President, Bulaw Welding Co., Chicago, Ill. Award: $508.77. Title of paper: "The Future of Arc Welding in the Cutting Industries." See Section IX, page 1257.

BURFORD, EDWARD F., Chief Draftsman, G. A. Harvey & Co., London, S. E. 3, England, co-author with Hugh B. Fergusson. Award: $101.75. Title of paper: "All-Welded Economic Type Boiler." See Section VIII, page 828.

BURYA, FRED F., 7306 S. E. 28th Ave., Portland, Ore. Award: $305.26. Title of paper: "The Welded Deep Well Turbine Pump." See Section IX, page 1118.

CAREY, L. J., Foreman, American Airlines, Inc., Chicago, Ill., co-author with Marvin Whitlock. Award: $7,326.46. Title of paper: "Arc Welding in Aircraft Heating." See Section II, page 91.

CHRISTIE, E., Welding Engineer, The Suffolk Iron Foundry (1920) Ltd., Stowmarket, Suffolk, England. Award: $152.63. Title of paper: "Desk and Seat Frames Fabricated by Arc Welding." See Section VI, page 681.

CURRY, A. S., Methods Supervisor, Nash Engineering Co., South Norwalk, Conn. Award: $305.26. Title of paper: "Redesign of Milling Fixture from Cast Iron to Welded Steel." See Section X, page 1356.

CURTIS, F. E., Engineer, Addressograph-Multigraph Corp., Euclid, Ohio, co-author with L. F. Mitchell and C. J. Hueber. Award: $712.28. Title of paper: "Arc Welding in Business Machinery." See Section IX, page 1126.

CURTISS, C. B., Engineer and Proprietor, Bay City Foundry & Machine Co., Bay City, Mich. Award: $152.63. Title of paper: "Motor-Truck Winch of Arc Welded Design." See Section IX, page 1098.

CZARNIECKI, JOHN, JR., Engineer, Kenworth Motor Truck Corp., Seattle, Wash., co-author with James W. Fitch. Award: $1,017.56. Title of paper: "Arc Welding for Economy in Constructing Beaching Gears for Large Planes." See Section II, page 119.

DALCHER, J. T., Consulting Engineer, 33 Rector Street, New York, N. Y. Award: $2,543.88. Title of paper: "A Modern Type of Welded Deck Barge." See Section IV, page 317.

DAVIS, C. A., JR., Engineer, Caterpillar Tractor Co., E. Peoria, Ill. Award: $1,729.84. Title of paper: "Design and Production of an All Welded Track Roller Frame Assembly." See Section I, page 62.

DAVIS, ERNEST, Chief Engineer, The Prosperity Co., Inc., Syracuse, N. Y. Award: $101.75. Title of paper: "Arc Welding Applied in Pressing Machine Manufacture." See Section IX, page 1146.

DAVIS, L. M., Hydraulic Test Engineer, Pennsylvania Water & Power Co., Baltimore, Md., co-author with J. M. Mousson. Award: $1,526.33. Title of paper: "Prewelding of Turbine Blades for Propeller Units of High Capacity." See Section IX, page 1027.

DEBUIRE, R., 44, rue Jules Fostier, Ronchin les Lille, (Nord) France. Award: $508.77. Title of paper: "The Use of Arc Welding for Building Hoisting and Conveying Equipment." See Section IX, page 1080.

DE CHARMS, RICHARD, Superintendent of Construction, Geo. A. Fuller Company, New York, N. Y. Award: $101.75. Title of paper: "Five-Span Deck-plate Girder Highway Bridge—Redesigned for Arc Welding." See Section V, page 587.

DE LAUBENFELS, C. R., Research Engineer, Lockheed Aircraft Co., Los Angeles, Calif. Award: $152.63. Title of paper: "Arc Welded Aeroplane Landing Gear Fork and Tests of Various Aircraft Welds." See Section II, page 126.

DE ROOY, IR. G., Designer and Commissioner of Submarines, Royal Dutch Navy, Vlissingen, Holland, co-author with Dr. P. Schoenmaker. Award: $3,764.94. Title of paper: "Modern Methods and Modern Steels in Welded Ship Construction." See Section IV, page 295.

DION, RALPH J., Welding Operator, Bloedel Stewart & Welch, Ltd., Bloedel, B. C., Canada. Award: $305.26. Title of paper: "Design and Construction of Arc Welded Motor Rail Car." See Section III, page 250.

DOREMUS, R. C., Refrigerating Engineer, Geo. B. Bright Co., Detroit, Mich. Award: $101.75. Title of paper: "Modernizing Michigan's Largest Brewery with Arc Welded Piping." See Section VIII, page 944.

DREWES, FRED H., Asst. to District Manager, Air Reduction Sales Co., Charlotte, N. C., co-author with Howard McCord. Award: $3,764.94. Title of paper: "Organizing and Operating a Job Welding Shop on a Business-like Basis." See Section VII, page 695.

DUBSING, ERNST, Foreman, Oliver Machinery Co., Grand Rapids, Mich. Award: $712.28. Title of paper: "Redesign of Bread Slicer Formerly Made of Cast Iron." See Section IX, page 1235.

FAVERTY, CLYDE B., Chief Engineer, The Ryan Car Company, Chicago, Ill. Award: $1,526.33. Title of paper: "Changing from Riveted to Welded Construction in Manufacture of Freight Cars." See Section III, page 228.

FERGUSSON, HUGH B., Director, G. A. Harvey & Co., London, S. E. 3, England, co-author with Edward F. Burford; see above.

FITCH, JAMES W., Engineer, Kenworth Motor Truck Corp., Seattle, Wash., co-author with John Czarniecki, Jr.; see above.

FOWLER, R. J., Structural Engineer, Diagrid Structures, Ltd., London, S. W. 1, England, co-author with Anant H. Pandya. Award: $11,397.06. Title of paper: "The All-Welded Diagonal Grid Applied to Plane and Spatial Structures." See Section V, page 411.

FREEMAN, E. J., Associate Professor, Clemson College, Clemson, S. C. Award: $3,764.94. Title of paper: "The Arc Welded Steel Frame Lecture Room Chair." See Section VI, page 659.

GARDNER, THOMAS H., Structural Engineer, Florida East Coast Railway, St. Augustine, Fla. Award: $203.51. Title of paper: "All Arc Welded Steel Railway Trestle." See Section V, page 614.

GARDNER, ELLIOTT, Naval Architect, Hyde Boat Yard, Scotia, N. Y. Award: $305.26. Title of paper: "Improved Methods of Building Small Pleasure Craft by Use of Arc Welded Steel." See Section IV, page 398.

GAUSS, HENRY F., Professor of Mechanical Engineering, University of Idaho, Moscow, Idaho. Award: $152.63. Title of paper: "Prime Movers Constructed Throughout by Electric Arc Welding." See Section IX, page 1041.

GIBSON, A. E., President, The Wellman Engineering Co., Cleveland, Ohio, co-author with M. W., (Mrs. A. E.), Gibson. Award: $13,941.33. Title of paper: "Commercial Weldery." See Section VII, page 730.

GIBSON, M. W., (Mrs. A. E.), Stockholder, The Wellman Engineering Co., Cleveland, Ohio, co-author with A. E. Gibson; see above.

GOODELL, JAMES, Designer, Kearneysville, W. Va. Award: $305.26. Title of paper: "Arc Welded Table Roller for Steel Mill Use." See Section IX, page 1204.

GRANT, EDMUND G., Associate Mechanical Engineer, California Institute of Technology, Pasadena, Calif. Award: $1,526.33. Title of paper: "Arc Welding and the 200-inch Telescope Project." See Section IX, page 1299.

HALE, W. CORY, Designing Structural Engineer, Jacksonville, Fla. Award: $152.63. Title of paper: "Arc Welded Steel in Theater Construction." See Section V, page 513.

HILL, MYRON T., Architect, Toledo, Ohio. Award: $508.77. Title of paper: "Welded Steel Frame for Residences." See Section V, page 535.

HOLLAND, RAY P., Aeronautical Engineer, Curtiss Aeroplane Division, Curtiss Wright Corp., Buffalo, N. Y. Award: $101.75. Title of paper: "The Potentialities of Arc Welding in Aeroplane Design." See Section II, page 149.

HOLLEY, E. C., Production Superintendent, St. Joseph Rwy., Light, Heat & Power Co., St. Joseph, Mo. Award: $101.75. Title of paper: "Fabrication and Erection of Stationary Steel Tank." See Section VIII, page 847.

HRUSKA, JOHN H., Metallurgical Engineer, Electro-Motive Corp., La Grange, Ill. Award: $2,543.88. Title of paper: "The Importance of Welding in the Body Construction of Diesel-Electric Locomotives." See Section III, page 204.

HUBBER, C. J., Engineer, Addressograph-Multigraph Corp., Euclid, Ohio, co-author with L. F. Mitchell and F. E. Curtis; see above.

JACOBS, B. A., Welding Operator, Phillips Petroleum Co., Bartlesville, Okla. Award: $101.75. Title of paper: "Revolving Adjustable Tilting Table Chuck." See Section X, page 1383.

JACOBSEN, ODD, Part Owner, Trosvik Verksted A/S., Brevik, Norway. Award: $203.51. Title of paper: "Design and Construction of an 800,000-Gallon Welded Storage Tank." See Section VIII, page 837.

JOHNSON, J. B., Chief, Material Branch, U. S. Army Air Corps, Dayton, Ohio, co-author with W. F. Savage. Award: $101.75. Title of paper: "Design of an Outer Wing Panel for Large Airplanes." See Section II, page 137.

KATZ, A. E., Welding Engineer, National Steel Car Corp., Hamilton, Ont., Canada. Award: $508.77. Title of paper: "Construction of a Light-Weight Passenger Coach Frame." See Section III, page 267.

KINKEAD, ROBERT E., Consulting Engineer, Welding, Cleveland, Ohio. Award: $8852.94. Title of paper: "Manufacture of Composite Metals by Carbon Arc Welding." See Section IX, page 1192.

KIRSHTNER, ERNEST, Foreman, Austin-Western Road Machinery Co., Harvey, Ill., co-author with Ernest L. Kirshtner, Jr. Award: $101.75. Title of paper: "Typical Arc Welded Jigs and Fixtures." See Section X, page 1395.

KIRSHTNER, ERNEST L., JR., Draftsman, Austin-Western Road Machinery Co., Harvey, Ill., co-author with Ernest Kirshtner; see above.

KLUTER, GEORGE L., Tool Supervisor, Warner & Swasey Co., Cleveland, Ohio. Award: $152.63. Title of paper: "Hardening Fixture for Long Steel Strips." See Section X, page 1367.

KUNS, RAY F., President, Trotwood Trailers, Inc., Trotwood, Ohio. Award: $203.51. Title of paper: "Redesign of Existing House Trailer to Permit Use of Arc Welding." See Section I, page 80.

LEWIS, JAMES T., JR., Assistant Works Manager, The Cleveland Crane & Engineering Co., Cleveland, Ohio. Award: $712.28. Title of paper: "Development of a Welding Fixture." See Section X, page 1339.

LOGEMAN, R. T., Engineer, American Bridge Company, Chicago, Ill. Award: $101.75. Title of paper: "Steel Facing for Dams." See Section V, page 643.

MACDONALD, A. F., Designing Engineer, American Bridge Co., Pittsburgh, Pa., co-author with R. F. Bergmann; see above.

MACNISH, CHARLES F., Engineer of Structural Design, Corps of Engineers, U. S. Army, St. Louis, Mo., co-author with Howard E. Boath; see above.

MACY, ROBERT H., Hull Designer, Newport News Shipbuilding & Dry Dock Co., Newport News, Va. Award: $1,017.56. Title of paper: "Savings in Cost and Weight by Welded Construction of a Railroad Car Float." See Section IV, page 345.

MARRS, G. O., Consulting Engineer, Universal Equipment Co., Denver, Colo. Award: $305.26. Title of paper: "Arc Welded Machine for Oxidizing Roast of Pyritic, Gold-Bearing Ore." See Section IX, page 1324.

MATTER, G. O., Mechanical Consulting Engineer, Portland, Ore. Award: $712.28. Title of paper: "Redesign of a Rotary Plow for Arc Welding." See Section IX, page 1213.

McCord, Howard, Foreman of Welding Dept., W. G. Jarrell Machine Co., Charlotte, N. C., co-author with Fred H. Drewes; see above.

McIntosh, S. Fraser, Vice President, Insulated Steelbilt Structures, Inc., Amsterdam N. Y. Award: $712.28. Title of paper: "Application of Arc Welding to Single-Frame Structure for Single or Multiple Dwellings." See Section V, page 527.

Mellon, T. C., General Superintendent, Worthington Pump and Machinery Corp., Buffalo, N. Y. Award: $508.77. Title of paper: "Large Two-Position Drill Jig Arc Welded from Rolled Steel." See Section X, page 1350.

Meyer, Arnold, Mechanical Engineer, The Heil Company, Pewaukee, Wis. Award: $508.77. Title of paper: "Trailerized Tanks." See Section I, page 52.

Midnight, Stanley A., Structural Designer, American Shipbuilding Co., Cleveland, Ohio. Award: $1,322.82. Title of paper: "Redesign of Midship Section of Great Lakes Bulk Freighter for Arc Welded Construction." See Section IV, page 333.

Mills, Frederick, Chief Draftsman, Mechanical Branch, Western Australian Gov't Railways, Midland Junction, Western Australia. Award: $3,764.94. Title of paper: New Design for Steam Locomotive Frame." See Section III, page 165.

Mitchell, L. F., Chief Engineer, Addressograph-Multigraph Corp., Euclid, Ohio, co-author with F. E. Curtis and C. J. Hueber; see above.

Mousson, J. M., Hydraulic Engineer, Safe Harbor Water Power Corp., Baltimore, Md., co-author with L. M. Davis; see above.

Muller, John F., Power Transmission Engineer, American Pulley Company, Philadelphia, Pa., co-author with G. C. Munoz. Award: $712.28. Title of paper: "Oil Pump Motor Base of Arc Welded Design." See Section IX, page 1176.

Munoz, G. C., General Manager, American Pulley Company, Philadelphia, Pa., co-author with John F. Muller; see above.

Pandya, Anant H., Chief Engineer, Diagrid Structures, Ltd., London, S. W. 1, England, co-author with R. J. Fowler; see above.

Perkins, Sumner E., Chief Mechanical Engineer, Flintkote Co., Los Angeles, Calif. Award: $101.75. Title of paper: "Welded Pipe Lines for Paper Board Cylinder Machine." See Section VIII, page 910.

Print, Henry P., Senior Partner, Print Bros., Eynsham, Oxon, England. Award: $203.51. Title of paper: "Application of Electric Arc Welding to a Pair of Wrought Iron Candlesticks." See Section VI, page 689.

Redline, Ralph H., Welding Supervisor, The American Locomotive Co., Dunkirk, N. Y. Award: $1,322.82. Title of paper: "Design and Cost of Locomotive Boiler of Fusion-Welded Construction." See Section III, page 217.

Reiff, Stanley G., Secretary and Design Engineer, General Construction Company, Omaha, Nebraska. Award: $305.26. Title of paper: "A Completely Arc Welded Highway Bridge for Secondary Roads." See Section V, page 604.

Rockenstire, W. C., Assistant Superintendent, American Locomotive Co., Schenectady, N. Y. Award: $712.28. Title of paper: "Design of an Arc Welded Locomotive Tender Tank." See Section III, page 276.

Rose, R. S., Chief Engineer, Wentworth & Irwin, Inc., Portland, Ore. Award: $203.51. Title of paper: "New Bus Bodies by Welding." See Section I, page 44.

Savage, W. F., Aeronautical Structural Engineer, U. S. Army Air Corps, Dayton, Ohio, co-author with J. B. Johnson; see above.

Schoenmaker, Dr. P., Chief Metallurgist and Consulting Welding Engineer, Smit-Transformerworks, Nijmegen, Holland, co-author with Ir. G. de Rooy; see above.

SCHULTZ, HARRY L., Draftsman, The Cleveland Punch & Shear Works Co., Cleveland, Ohio. Award: $508.77. Title of paper: "High Speed Metal Forming Press." See Section IX, page 1005.

SEABLOOM, ERIC R., Research Welding Engineer, Crane Company, Research Laboratories, Chicago, Ill. Award: $101.75. Title of paper: "Elimination of Flange Joints on High-Pressure, High-Temperature Piping and Valves." See Section VIII, page 924.

SEDGWICK, H. A., General Superintendent, Cutler Hammer, Inc., Milwaukee, Wis. Award: $101.75. Title of paper: "Arc Welded Dies." See Section X, page 1387.

SEIPEL, ARNOLD A., Hydraulic and Mechanical Engineer, Bureau of Reclamation, Denver, Colorado. Award: $3,764.94. Title of paper: "Arc Welded Scroll Cases for Hydraulic Turbines." See Section VIII, page 852.

SEVERINGHAUS, NELSON, Superintendent, Consolidated Quarries Corp., Lithonia, Ga. Award: $1,526.33. Title of paper: "New Design of Side-Dump Semi-Trailer." See Section I, page 29.

SHERMAN, R., Assistant to Consulting Engineer, Messrs. Steel Ceilings, Ltd., Hayes, Middlesex, England. Award: $203.51. Title of paper: "Radical Departure in the Construction of Large Roofs." See Section V, page 489.

SHOEMAKER, E. L., Chief Engineer, Warner Company, Philadelphia, Pa. Award: $101.75. Title of paper: "A Design and Method of Constructing Welded Towboat Hulls." See Section IV, page 356.

SHOEMAKER, ROBERT C., Engineer in Charge of Equipment, Warren Northwest, Inc., Portland, Ore. Award: $508.77. Title of paper: "Design of an Asphalt Paving Plant of Maximum Capacity, Minimum Weight and Maximum Mobility." See Section IX, page 1158.

SILVEN, HERBERT A., Machine Designer, Norton Company, Worcester, Mass. Award: $712.28. Title of paper: "Hydraulic Manifold Designed for Arc Welding." See Section IX, page 1132.

SIMONS, WILLIAM, Superintendent of Shops, Cliffs Dow Chemical Co., Marquette, Mich. Award: $203.51. Title of paper: "Arc Welded Steel Locomotive Tender Frame." See Section III, page 289.

SPANNER, EDWARD FRANK, Managing Director, Messrs. Spanner Thimble Tube Boiler, Ltd., London, E. C. 3, England. Award: $1,322.82. Title of paper: "Welding as Applied to Thimble Tube and Watertube Boilers." See Section VIII, page 814.

STEARNS, G. M., Assistant Professor, Petroleum Engineering, University of Oklahoma, Norman, Okla. Award: $2,543.88. Title of paper: "Arc Welded Oil Well Casing Provides Substantial Saving." See Section VIII, page 801.

STEELE, F. E., Designing Engineer, Shreveport, La. Award: $152.63. Title of paper: "Application of Arc Welding to Manufacture of Sheet Steel Bath Tub." See Section VI, page 683.

STONE, HERBERT, Assistant Works Manager, Markham & Co., Ltd., Chesterfield, England. Award: $2,747.39. Title of paper: "Arc Welded Fabrication of Spiral Casing for Water Turbine." See Section IX, page 1016.

STREITHOF, C. PERRY, Structural Engineer, Dravo Corporation, Pittsburgh, Pa. Award: $101.75. Title of paper: "Welded Wharfboat Built from Six Obsolete Steel Barges." See Section IV, page 368.

THOMASSON, H., Welding Engineer, Canadian Westinghouse Co., Ltd., Hamilton, Canada. Award: $2,747.39. Title of paper: "Organization, Equipment and Operation of a Plant Weldery." See Section VII, page 761.

THOMSON, JOHN, Works Director, Sir William Arrol & Co., Ltd., Bridgeton, Glasgow, S. E., Scotland. Award: $712.28. Title of paper: "An Arc Welded Rotary Planing Machine." See Section IX, page 957.

TREAT, ROBERT S., Bridge Designer, Connecticut State Highway Department, Hartford, Conn., co-author with John F. Willis. Award: $1,526.33. Title of paper: "An Arc Welded Two-Span Rigid Frame for Highway Grade Separation." See Section V, page 562.

TSAGARIS, J. G., Welding Engineer, Erie Steel Construction Co., Erie, Penna. Award: $508.77. Title of paper: "Construction of an All-Welded Building." See Section V, page 463.

UPSON, RALPH H., Consulting Engineer, Kay Products Co., Ann Arbor, Mich. Award: $1,322.82. Title of paper: "Arc Welding in Aircraft." See Section II, page 107.

VAN ETTEN, SCOTT, Manager and Superintendent, Colvan Stoker Co., Columbus, Ohio. Award: $508.77. Title of paper: "An Arc Welded Coal Stoker for Residence and Other Heating." See Section IX, page 1223.

VENTER, H. C., Superintendent of Shops, Southern Pacific R. R. Co., Sacramento, Calif. Award: $508.77. Title of paper: "Fabricated Parts for Locomotives and Cars." See Section III, page 282.

VERSON, HAROLD, Chief Engineer, Verson All Steel Press Co., Chicago, Ill. Award: $508.77. Title of paper: "Redesign of a Cast Iron Planer for Arc Welded Steel Construction." See Section IX, page 966.

WAHL, HAROLD F., Contact Man, Willamette Hyster Co., Portland, Oregon. Award: $101.75. Title of paper: "A Tilting Fixture." See Section X, page 1371.

WATSON, J. D., Engineer, The Madras & Southern Mahratta Rwy. Co., Ltd., Park Town, Madras, India. Award: $712.28. Title of paper: "Welded Open Frame, or Vierendeel Girders, Designed as Main Strength Members of Railway Coaching Stock." See Section III, page 258.

WATTS, J. MURRAY, Naval Architect, Philadelphia, Pa. Award: $508.77. Title of paper: "Arc Welded Steel Construction of Auxiliary Cutter Yacht." See Section IV, page 391.

WEINBERGER, E. W., Proprietor, Weinberger Garage, Mott, North Dakota. Award: $1,526.33. Title of paper: "How to Use the Arc to Increase Business in the Garage." See Section VII, page 712.

WEISS, HOWARD, Engineer, The Dingle-Clark Co., Cleveland, Ohio. Award: $305.26. Title of paper: "A Pipe Line for Steel Mill Service." See Section VIII, page 869.

WENDT, H. C., Chief Engineer, Hackney Bros. Body Co., Wilson, N. C. Award: $3,764.94. Title of paper: "The Arc Welded Steel School Bus Body—Its Social and Economic Advantages." See Section I, page 3.

WHITEHOUSE, HAROLD C., Architect and Contractor, Senior Partner, Whitehouse and Price, Spokane, Wash. Award: $305.26. Title of paper: "Lighting Fixture in Iron and Arc Welding." See Section VI, page 686.

WHITLOCK, MARVIN, Engineer, American Airlines, Inc., Chicago, Ill., co-author with L. J. Carey; see above.

WHITAKER, LLOYD A., Chief Engineer, Thomson-National Press Co., Franklin, Mass. Award: $712.28. Title of paper: "Platen Press Frames Arc Welded." See Section IX, page 1268.

WILKIE, LEIGHTON A., President, Continental Machine Specialties, Inc., Minneapolis, Minn. Award: $203.51. Title: "The Evolution of Contour Machining." See Section IX, page 988.

WILLIS, JOHN F., Engineer of Bridges, Connecticut State Highway Department, Hartford, Conn., co-author with Robert S. Treat; see above.

WUNSCH, HARRY, Mechanical Engineer, Silent Hoist Winch and Crane Company, Brooklyn, N. Y. Award: $305.26. Title of paper: "A Refuse Collection Vehicle Body." See Section I, page 36.

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AUTOMOTIVE

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ARC WELDING in DESIGN MANUFACTURE and CONSTRUCTION

SECTION I
AUTOMOTIVE

Chapter I—The Arc Welded Steel School Bus Body —It's Economic and Social Advantages

By H. C. Wendt,
Chief engineer, Hackney Bros. Body Co., Wilson, N. C.

My organization decided that the growing demand for all-steel school buses could no longer be denied. This was not a new thought with us. For over a year a completely designed all-steel school bus body had been "off the board". Unfortunately a complete analysis of the tools, dies, fixtures and new equipment required to build it put this particular design definitely out of our reach. If memory serves correctly, our required investment in these items ran in the neighborhood of $60,000.00 which was prohibitive for a small organization that had just weathered a depression and had no particular reason for believing that business conditions would improve in the near future

In spite of our decision the pressure of competition made it more and more imperative that we produce an all-steel school bus body. Finally the solution arrived. A large manufacturer of automotive and sheet metal stampings had likewise awakened to the fact that the wood or "composite" school bus bodies had become obsolete, not only because of a growing steel mindedness on the part of the public but also because of active legislation against them in many states. So they conceived the idea of building parts for an all-steel school bus body and offering them, complete for assembly, to various body builders who were not already in production on all-steel.

Two important factors entered into their decision. In the first place, they already owned a large number of expensive dies for doors, window openings and other difficult parts. Secondly, the cost of the remaining dies could be amortized over the large production that would be obtained by selling a large list of manufacturers. Thus, no one concern would be faced with the unwelcome prospect of paying huge sums for tools and equipment before producing a single body.

This proposition looked very attractive to us and we spent weeks of study over their drawings and specifications. It appeared, from an engineering standpoint, that the body was amply designed for strength, ruggedness and serviceability. Tolerances called for indicated that mating parts would fit snugly and with correct alignment of bolt and rivet holes. This having been determined, we sent a group of department heads to the manufacturers' plant to view and study the sample body which had been built and to make independent reports. Inasmuch as these reports were uniformly favorable we decided to contract for approximately 200 bodies. Our schedule for "composite" bodies was

set at approximately 600 and we felt that the additional 200 all-steel bodies would practically fill us to capacity during the three to three and one half months that normally constitute the school bus season.

We felt, and still feel today, that the price at which we bought our body parts was an attractive one. It compared favorably with the estimated manufacturing cost of the parts we had designed in the all-steel body previously mentioned. When we added a reasonable amount to our estimated manufacturing cost for tool and die amortization, our cost ran very much higher. Therefore, we concluded that we had made a good bargain and went ahead.

Not long after assembly started we discovered that the assembly labor in man hours was far above any body with which we had had previous experience. We had expected a higher assembly cost than that required for our composite bodies and had provided for this extra in establishing our selling price. We quickly found, however, that this increase was so great that it wiped out our entire margin of profit and more. Our only solution was to raise our selling price which, in turn, put it beyond the means of the purchaser in our natural market which is the Southeastern portion of the United States. Higher prices for bodies were being paid in other sections of the country but when we tried to sell our bodies in other sections, our cost of sales became so great as to again wipe out our margin of profit. Needless to say, we suffered a severe loss on this initial attempt to break into the all-steel bus body business. (Further on, in a comparison between this all-steel body and our present all-steel body the reason for this failure and relative costs will be discussed.)

We were again out of the all-steel body business. We felt that we had learned our lesson and would confine ourselves to "composite" types. It soon developed, however, that such a policy was exactly the equivalent of going out of business as the tide toward all steel was running more and more strongly every day.

During the autumn and winter, we put another all-steel bus body on the boards. Nothing was sacrificed in design, strength, weight, ruggedness or serviceability. The main difference was that this body was designed to be assembled by arc welding. And on this design we really "went to town". It put us in the low price bracket which our territory required, without putting the body into the "village blacksmith" type of body usually encountered in the low-price field. It put us into all-steel manufacturing at an unbelievably low tool, die, and equipment cost. It put our all-steel manufacturing on the profit side of the ledger. It gave us sales volume.

The intent of this paper is to compare, as far as possible, the relative costs of assembling and manufacturing two bodies of, roughly, the same width, height and length, the same passenger capacity and the same strength, ruggedness and durability; one designed for assembly by mechanical means, to be referred to as Body No. 1, the other designed for assembly by means of arc welding, to be referred to as Body No. 2. A body of the type to be discussed is shown in Fig. 1. This being the case, probably the best way to describe the two bodies is to give only the assembly procedure in detail. If detailed drawings of all individual parts were incorporated in this paper they would

easily number close to five hundred and the task of separating the wheat from the chaff would be prodigious.

In describing the assembly of body No. 1, the first discussed in the introduction, the instructions of the parts manufacturer will be set down verbatim. The item numbers refer to the number shown on the photographic reproductions.

Description and Assembly Instructions Body No. 1.—An assembly stand should be provided in the body manufacturer's plant, and the top of this stand should be equipped with studs spaced to receive the holes in the mounting plates furnished by the parts manufacturer.

The rear frame assembly is furnished as a complete unit consisting of the rear underbody channel with floor and back extensions, the right and left last side posts, the four rear posts, and the upper cross channel with emergency door stop plate. These six posts included in this assembly are equipped with brackets, etc. All holes are provided and all welding is done by the parts manufacturer.

This rear frame assembly should be mounted to overhang the back of the assembly stand. This is the first operation in the body manufacturer's plant. This assembly is also provided with bearing plates to rest on

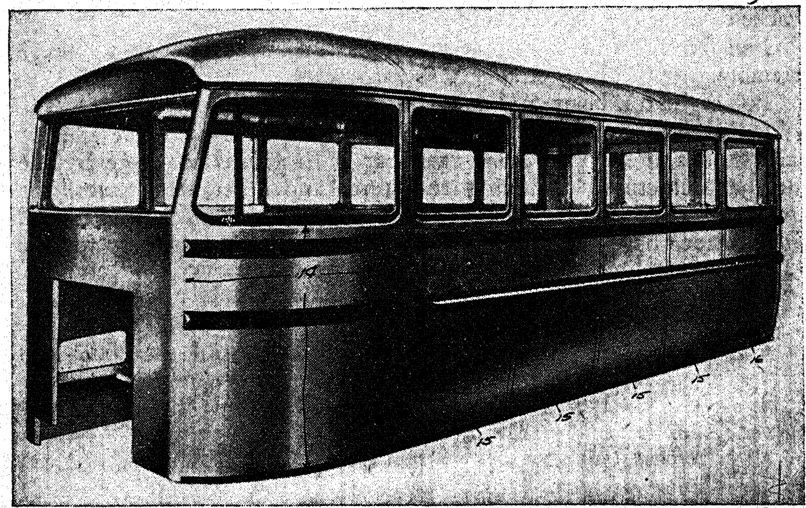

Fig. 1. Type of school bus body to which arc welded construction was applied.

chassis extension, and the assembly stand should be provided with extensions to support this assembly on these bearing plates.

The four standard cross frame assemblies are furnished as four complete units; each consisting of the underbody cross channel, body side posts and roof rib, all welded into a single unit. These units are punched for the few bolts required, slotted for clinch strips; and equipped with the following:—

Nut retainer inserts for fastening roof rib covers; top brackets for longitudinal channels and window post covers; center bracket for window

post covers, seat back and for window regulator, board or panel; lower bracket for window regulator panel; felt retainer channel for bottom of window when lowered; two pairs of gusset plates welded over underbody channel and side post joints, with top edges of gusset plates curled to bear on top of channel; mounting plates welded to underside of underbody channel, punched with multiple holes for attaching to mounting clips.

All the above equipment is provided, and all the welding is done in the parts manufacturer's plant.

These four assemblies are placed on the assembly stand studs, in the body manufacturer's plant. This is the second assembly operation.

To complete the body skeleton, ready for the outer shell panels, the following procedure was used: Items apply to Fig. 2.

Item No. 3:—Place the entrance cross frame assembly on the assembly stand. In addition to the above specification, this No. 3 assembly is also provided by the parts manufacturers with underbody brackets for front members, step plate hanger and entrance door slam strip.

Item Nos. 4 and 5:—Bolt the two No. 4 and the eight No. 5 top longitudinal channels to the top brackets in the post, and with the same bolts attach the eight standard longitudinal connectors.

Item Nos. 7 and 8:—Bolt the three front underbody beams to the brackets on the entrance cross frame (3) assembly.

Item Nos. 9 and 10:—Bolt left top beam and connector to No. 3 assembly.

Bolt right top beam and connector to No. 3 assembly.

Install front assembly, bolting the brackets on same to the ends of parts 7, 8 and 9. This front assembly is furnished complete by the parts manufacturer, including the inner and outer steel posts, the inner and outer steel dash panels, the plywood filler, the inner and outer header bars, the bolting brackets, and continuous hinge for the

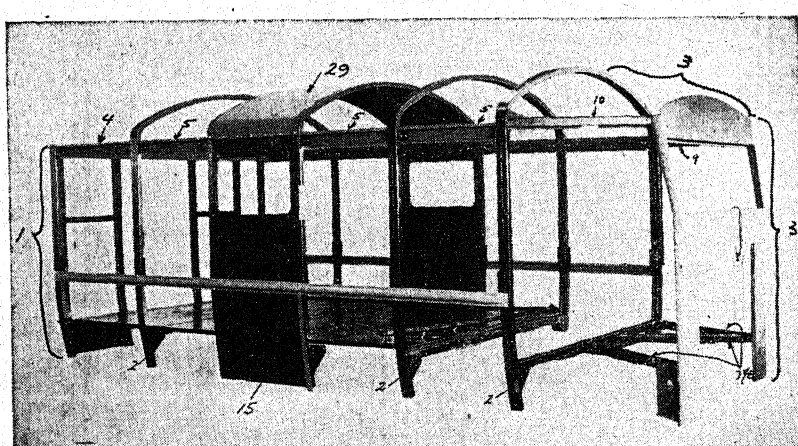

Fig. 2. Mechanically assembled body ready for outer shell panels.

windshield, all completely assembled and welded. The hinge for the entrance door is furnished with the door.

The steel body skeleton is now completed, ready for the outer shell panels. (See Fig. 2).

Item No. 14, (See Fig. 1):—Install driver's window panel assembly. This assembly consists of the outer window panel, the inside regulator panel, the double dividing channel between the drop window and the stationary window, and the inner channels and flanges for fastening to body posts. All holes are punched in this assembly and in adjoining floor and top beam members, and nuts are provided in the front assembly for fastening this driver's window assembly to same.

Item No. 15, (See Fig. 1):—Hang the eight standard side panels on the body skeleton. The top edge of these panels is flanged to form a hook which fits over the top flange of the top longitudinal channel. No bolts should be installed as yet. This panel is punched for drip moulding bolts, is provided with flanged and recessed window opening with spotwelded retainer strip, the upper belt moulding, the holes for rub rail, the skirt moulding, and reinforcing flange. The width of these panels fits between the slots in the body posts.

Item No. 16, (See Fig. 1):—Hang the last side window panel on either side of the body in the same manner.

Hang the rear corner stampings by temporary installation of two bolts to support each corner from the top channel.

Bolt the rub rails, first to the body posts, and then to the side panels. The rub rails form the lower belt moulding the entire length of the five windows.

The installation of the rub rail has completed the longitudinal bracing of the body, and the entire body may now be removed from the assembly stand if so desired. In this case it should be placed on another standard table of approximately the same length and width, which need not have the spacing studs.

Install rear center lower panel and bolt same to rear frame assembly.

Hang the two rear window panels, hooking the flange on the top of the panel over the top channel of the rear frame assembly.

Install the four rear clinch strips. Two men can do this very rapidly. The man on the outside of the body places the clinch strip in position with the clinch lugs through the slots in the body posts, and holds the strip tight against the body, using a heavy dolly. The man on the inside spreads the clinch lugs and hammers them down tight. (A handy tool for this purpose consists of two average size chisels welded together, one chisel being ground to a narrow edge and the other to a blunt edge. A few blows on the narrow chisel spreads the clinch lugs, a few blows with the blunt chisel spreads them further, and a few blows with the hammer in the other hand flattens the clinch lugs securely to the inner surface of the body posts). These clinch strips hold the window panel sheets tightly to the body posts, and yet permit of slight weave, as there are no bolts at this point. The elimination of bolts leaves the outer surface of the joints between the body sections perfectly smooth and thereby improves the appearance of the finished body.

Install the side clinch strips in the same manner. There are six

joints on each side of the body to be covered in this manner, and each clinch strip is in two parts, above and below the rub rail.

Place the front floor plate assembly in position, with the rear flange entering the groove in the top of underbody channel. Bolt the front floor plate down to the front underbody beams and to the front assembly. This front floor plate assembly included the step riser and flange.

Bolt the step plate to the flanges provided to support same.

Install rubber strips in the metal weatherstrips and tighten same in cornice brake or by hammering. Bolt same to the short longitudinal flanges of the floor panels.

Place the four standard floor panel assemblies in position, with the front and back flanges entering the grooves in the top of the underbody channels.

Place the rear floor panel assembly in position, in the same manner There are no holes in the floor panels, as no separate bolting is required.

Lay the five overfloor channels in the grooves formed by the flanges of the floor panels. The flat extension on the ends of these channels is for the purpose of closing the floor space inside the body posts. Bolt these overfloor channels through the underbody channels, thus securely tying down and wedging the entire floor.

Holes are also provided in the vertical flanges of the underbody channels for horizontal bolts to further tighten these floor joints and these bolts may now be installed if desired.

Place the rear roof panel in position with slots over the slots in roof rib. (The slots in this rear roof panel are punched wide to allow for any variation in these hammered panels). Place rear drip moulding over the back edge of this roof panel; bolting through drip moulding, rear roof panel, rear window panels, and rear upper cross channel.

Item No. 29, (See Fig. 2):—Lay the four standard roof panels in position, starting at the back so that the laps will be in the right direction.

Place the front roof panel in position, overlapping the first standard roof panel.

Place weatherproofing strips, (friction and filler tape, parafinned cork, creosoted felt, etc.) a strip on either side of the overlapping roof joints. Install the roof clinch strips in the same manner as previously described, starting in the center of the roof and working both ways. Leave the ends of the clinch strips loose beyond the last clinch lugs, until after the next operation.

Bolt the side drip mouldings through roof panels, side panels, and longitudinal channel. Now cut the ends of weatherproofing strips and bolt the ends of roof clinch strips over drip moulding.

Bolt on the aluminum front and rear corner roof mouldings.

The outer shell of Body No. 1 is now completed.

Inside Trim Stampings.—Install the five roof rib covers and fasten same with screws through hole provided in cover and nut provided in roof rib.

Install the inside trim panels under the two rear windows.

Install the two rear door post covers, with screws to nuts in posts.

Install two rear corner covers in the same manner.

Install the ten side window post covers in the same manner.

Place glass and rubber between the inner and outer panel assemblies of the sedan door and assemble same with through bolts. The continuous hinge is provided by the parts manufacturer, but glass and rubber are not.

Assemble and install the emergency door.

Cut through body shell for wheelhouse, location depending upon chassis, and install same. The wheelhouse will be provided by the parts manufacturer with finished fender edge and with extended back plate, and the special angles for bolting to body side panels, body posts, and floor panels are provided.

The above assembly brought Body No. 1 to the paint shop; minus glass, minus seating and minus paint.

Insofar as is possible, the following description of Body No. 2 will bring it up to the same condition as Body No. 1. The variations in the condition of the two bodies will be discussed after relative costs have been brought out.

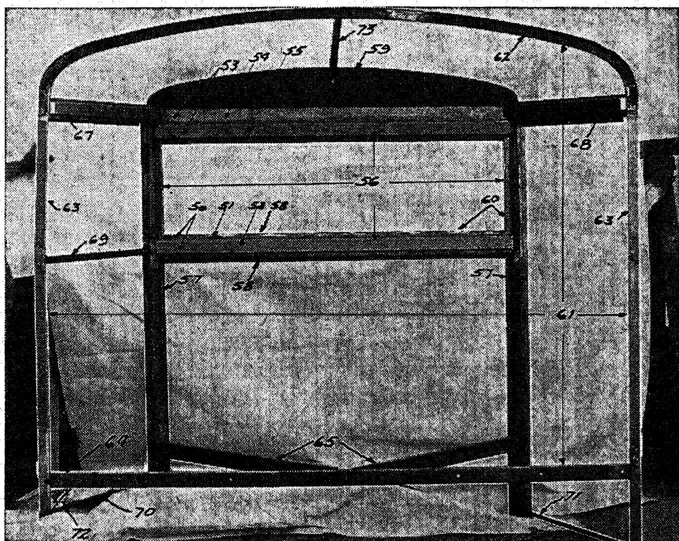

Fig. 3. Arc welded body—rear view of front end frame assembly.

The item numbers in the following discussion follow the same principle as outlined for body No. 1. The item numbers will be found on photos.

Description and Assembly of Body No. 2.—Refer to Fig. 3. Cowl bar, and cowl bar reinforcement assembly (50):—Cowl bar (51) and cowl bar reinforcement (52) were nested in a jig and spotwelded.

Windshield header and header reinforcement assembly (53):—The

header (54) and reinforcement (55) were nested in a jig and spotwelded.

Windshield assembly:—The two assemblies described above (50 and 53) were positioned in the windshield assembly jig and the windshield posts (57) (furnished completely assembled by means of spot and arc welding) were inserted and the four tabs of the cowl bar and header reinforcements were fastened to the posts by means of ¼ No. 20 self tapping screws. Then, working from the front of the body, the ends of the flanges and web of the modified channel forming the cowl bar were arc welded to windshield post.

Exactly the same procedure was followed in arc welding the windshield header to the windshield post. The upper dash panel (58) was then inserted, spot welded to the cowl bar at its lower edge and arc welded to the windshield posts at the front. These welds were ground off for finish. The forehead (59) was then placed in position, the upper edge of windshield header spot welded to it and the ends of the forehead were welded to the outside corners of the windshield post. (These welds were not ground off as they were later hidden by the windshield visor. The installation of the forehead and upper dash panel concealed all previous arc welds. In our design we constantly kept in mind not only the desirability of creating a strong welded structure but also the desirability of concealing every weld in order that the body would have a strong aesthetic appeal by reason of smooth clean looking surfaces both inside and out.)

All edges of flanges in the windshield opening were then arc welded at about 6″ intervals (60, Fig. 3), thus completing the windshield assembly. (These welds were not ground off as they were later concealed by

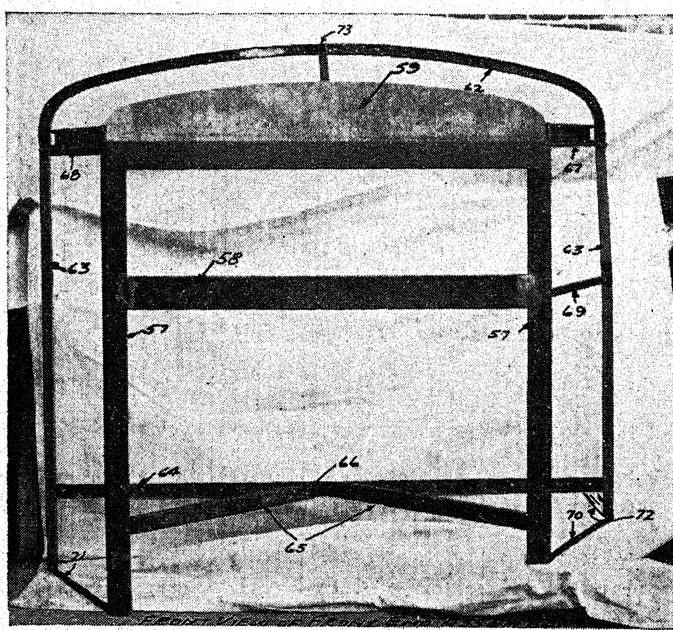

Fig. 4. Arc welded body—front view of front end frame assembly.

the windshield glass rubber). A brief study of this assembly will disclose the strength and rigidity inherent in the tubular windshield posts and the double tube construction formed by the members at the cowl and header.

No. 1 Post, rib and floor bearer assembly (61):—The arc welding of the rib (62) to the posts (63) and of the floor channels (64) to the posts, followed.

Front floor diagonal assembly (65):—The strap (66, Fig. 4), was arc welded to the diagonal channels.

Front end assembly:—The windshield assembly and post and rib assembly were placed in the front assembly jig. The drivers' window header (67, Figs. 3 and 4), and front door header (68) were clamped into the jig and welded to the No. 1 posts and windshield posts, all welds being concealed from the inside and later from the outside by application of the front roof panel. The driver's window belt rail (69) was inserted and welded to No. 1 post and windshield post. The diagonal assembly was then positioned and arc welded to the No. 1 floor channel and windshield post. The left hand front skirt rail (70) and step well angle (71) were then locked in position and arc welded to No. 1 and windshield posts. The front floor, to which the step well had been spot welded, was then dropped in place and the vertical flanges of the step well were arc welded on approximately 4″ centers to the No. 1 post and floor channel (thus forming a gusset against lateral distortion) and to the windshield post. A diagonal gusset (72) was arc welded to the left hand No. 1 post and floor channel. The front tab of the spline rail (73) was bolted to the forehead and arc welded to the rib, an arc weld being made from the inside of the channel and thus concealed. The windshield visor was then placed against the forehead, and spot welded thereto and to the sides of windshield post. A rubber seal was placed along the upper edge, the front roof panel laid on, bolted to the forehead and spot welded to the front door and driver's window header, thus completing the front assembly.

Rear assembly:—(Refer to Fig. 5). The No. 6 post (74), floor (75), (already assembled to floor channels (76) by spot welding) rear window posts (77), and rear door posts (78) were clamped in the rear assembly jig in the order named. The rear floor front channel was arc welded to the No. 6 post and both sides of the four rear posts were arc welded to the rear floor assembly. Both sides of these four posts were then arc welded to rear roof rail (79). The belt rails (80) were then positioned and arc welded to the rear posts.

The diagonal gussets (81) were then placed in position and arc welded at about 6″ intervals to the adjoining posts. The skirt rail angles (82) were then clamped in position and arc welded to the six posts which they contacted thus completing the rear assembly.

Floor angle (82) and rub rail angle (83) assembly:—(See Fig. 6). Lest the reader criticize the mass of these members in proportion to the remainder of the structure, let it be said that in this respect we have been influenced by the experience of the State of North Carolina, (incidentally the largest bus fleet operator in the world), with crash accidents over a period of years. The development of this structure has been gradual and with every change toward greater mass the record of serious accidents to passengers due to side crashes has decreased. Naturally there is

no limitation to the weight of metal that can be put in at this joint but the present structure has a 100% record of no penetration into the interior of the body regardless of the character of the accident. It would be simple to design a light weight structure that would have better deflection characteristics than the one adopted but it is doubted that such a unit would have the energy absorption and energy distribution characteristics under impact that the present structure contains.

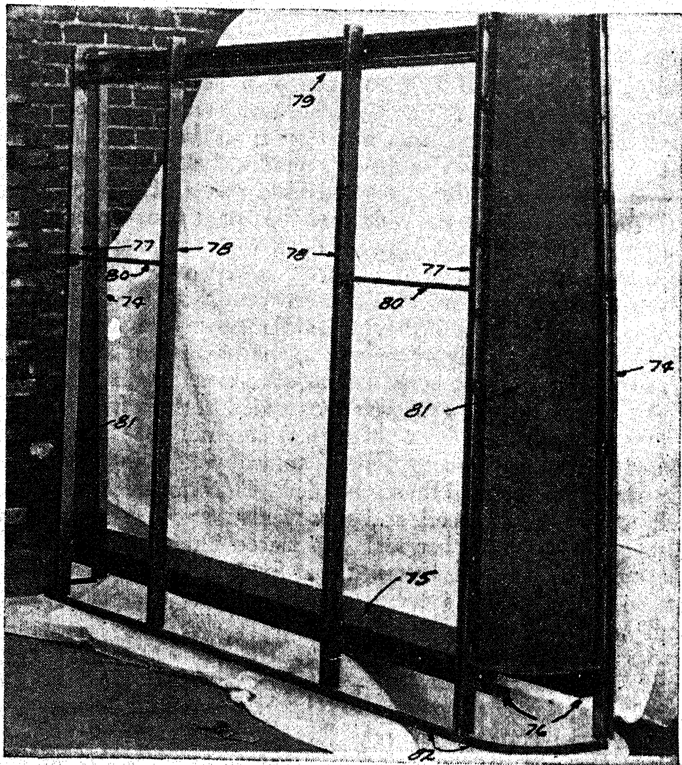

Fig. 5. Arc welded body—rear frame assembly.

Side frame assembly:—(Refer to Fig. 6). The floor angle and rub rail angle assembly were placed in the side assembly jig. In order, the side roof rails (84), belt rails (85), skirt rail angles (86) and side posts (87) were positioned against their retaining stops and clamped in position. The posts were then arc welded on both sides to the floor and rub rail angles for the full length of their vertical intersections. The skirt rail angles were arc welded to the bottom of the posts. The belt rails were then arc welded on the underside to both sides of the post and lastly the roof rails were welded on the lines of both horizontal and vertical intersections to both sides of the posts.

Complete floor assembly:—The elements in 88 and 89 above were bolted together with seven $\frac{5}{16}$ bolts per section and placed on a long, wheeled trestle in preparation for final assembly.

Final frame assembly:—(Refer to Fig. 6). The complete side frame assemblies were positioned on the floor assembly with the side posts resting in the notches formed at the intersections of the floor sheets. The side assemblies were squared to the floor line and clamped in position. While in position the floor angles were bolted through floor and floor channels by first drilling through the latter two using pre-punched holes in horizontal leg of floor angle as a guide. At this point field welds were made. The roof ribs (62) were slipped over the stub ends of the posts and by means of a movable jig were properly distanced from the floor line and accurately located so that the surfaces of the ribs were located in the same curved plane. The upper and lower intersections of posts and ribs were then arc welded. Diagonal gussets (93) were then joined to each post and floor channel by arc welds to prevent lateral distortion. The triangle of floor channel, gusset and post was then completed by arc welding the ends of the floor bearers to their adjoining posts thus completing a stable structure against lateral distortion at this point. The front and rear assemblies were then slipped into position, the contacting floor members were bolted together and the free ends of skirt rails, floor angles, rub rail angles, belt rails and roof rails were welded, thus completing the entire frame assembly.

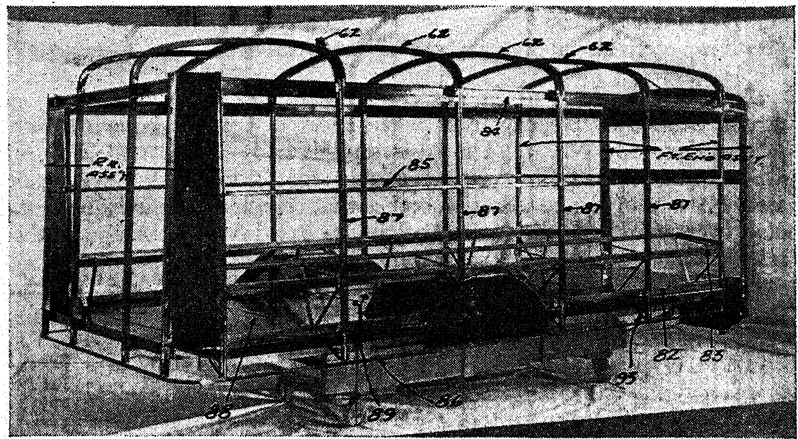

Fig. 6. Arc welded body ready for outer shell panels.

The side panels were equipped with bottom flanges bent through approximately 150 degrees. These flanges were hooked over the vertical legs of the skirt rail angles and the panels spot welded to the belt rails and to the post at which sheets were joined. The rear sheets were applied in a similar manner. All side and rear joints were covered with bolt-on mouldings.

Post cover panels were then applied and welded to the posts. These panels were equipped with flanges against which the window sash-channels registered.

Side window visors were then applied by welding through the roof rail flange.

In order to eliminate roof joints at every rib the center section was

made up of three panels running lengthwise of the body. The vertical flanges formed by the three thicknesses of 20 gauge metal stiffened the roof considerably and entirely eliminated the "drumming" effect frequently encountered in steel roofs.

The roof sheets were arc welded to the ribs on approximately 8-inch centers and the lower edges arc welded to the roof rails.

The joint between the center roof sheets and front and rear roof panels was welded. This section had considerable merit inasmuch as it was absolutely foolproof from the standpoint of roof leaks—the biggest "bugaboo" in steel bus construction. The rubber seal between the roof sheets and outside moulding was designed to prevent water entry. If, however, the joint was faulty at any point, the water merely ran down the inside of the rib and out at the bottom of the tubular posts.

The horizontal roof moulding was applied with self-tapping sheet metal screws.

The doors came to the body completely metaled inside and out with the hinge applied. They were hung in the door openings and secured by spot welding the hinges to the posts and, for further insurance, by applying self-tapping sheet metal screws staggered at approximately 8 inch intervals.

This operation brought the body up to the same point as body No. 1, i.e., completely metaled, without glass and ready for paint.

Comparative Costs of Bodies.—In the following cost summary, the writer "leaned over backwards" in an effort to present the best possible picture for body No. 1. The costs on this body varied widely during most of our production. A search of our records disclosed, however, one assembly run of ten consecutive bodies that represented our highest peak of efficiency and the costs given below are based on the average of these ten bodies.

BODY No. 1 (Mechanical Assembly)			BODY No. 2 (Arc Welded Assembly)		
Department	Labor	Burden	Department	Labor	Burden
1	.076	.143	1	.362	.563
2	8.923	8.726	2	4.041	3.977
4	2.169	2.073	4	7.733	9.199
6	2.246	3.864	6	2.552	4.637
8	10.771	10.401	8	3.696	3.736
9	1.666	1.723	9	.857	*S.S. 1.156
Sub. Assembly	1.123	*S.S. 1.618		19.241	24.298
	26.974	29.595			

LABOR	26.974 + 40.19%	LABOR	19.241
MATERIAL	146.506 + 159.48%	MATERIAL	56.461
BURDEN	29.595 + 21.80%	BURDEN	24.298
TOTAL	203.075 + 103.075% =	TOTAL	100.00
= increase body No. 1 over body No. 2 in %			

Our costs on body No. 2 became progressively lower with each production order. The first run of 25 bodies was quite high in cost and the last run of 25 was surprisingly low. These two runs were omitted

* S.S. stands for Social Security

and the average taken of the remaining intermediate runs. In spite of the fact that the cost of body No. 2 represents our average cost and the cost of body No. 1 represents our *best* cost the advantage in favor of body No. 2 is so startling as to be almost unbelievable. Actual cost figures on body No. 2 were proportioned downward to make the total cost equal 100 and the cost of body No. 1 was then proportioned to the same base.

It is not difficult to show that the gross savings accruing to industry—that is, the industry which concerns itself in the safe and economical transportation of school children, would be very large. According to statistics as of January 1, 1938, there were 84,061 school busses in operation in the United States. Some of these school bus bodies are purchased at approximately $400 each, others are purchased at approximately $2000 each. Some are "composite" or wood construction while others are all-steel. The trend toward all-steel, however, is so strong that it is a certainty that within a few years other types of construction will be legislated out of existence. It is calculated that the average cost of all-steel school bus bodies runs in the neighborhood of $750. Assuming that all of the school bus bodies now in operation in the United States were purchased at that price their total value would be $63,045,750. Investigation proves that body No. 2 is the only all-steel school bus body designed for arc welding. It must be true, then, that all other steel school bus bodies are designed for mechanical assembly. Now then, if all of these bodies had been designed for arc welding, and the same percentage saving in cost as described above had been enjoyed, the $63,045,750 worth of bodies would have come down to approximately $31,057,000.

The increased service life of welded construction over mechanical assembly is quite considerable and readily understandable. Once a bolt loosens in the relatively thin sheet metal sections in general use, the bolt holes rapidly elongate due to the wracking to which loose joints are subjected in service. Then it becomes impossible to tighten such joints and the body rapidly falls into such a state of disrepair that it becomes unsafe and must be scrapped. Welds, on the other hand, result in a complete fusion of adjoining parts thus forming joints that will not weave and gradually loosen up. Thus, when all parts of a body maintain their original relationship to one another the body remains sound and safe over a considerable period and obsolescence is held at a minimum.

Increased social advantage is provided to the State of North Carolina by the adoption of arc welded design. While that state transports more children to and from school than any other state in the Union, many children still must walk to school and many busses are so crowded as to present a definite moral hazard and unsafe operation. The fact that arc welded construction has resulted in such a saving that many additional busses can be purchased will alleviate the above conditions to a greater extent every year and the entire community benefited thereby.

Chapter II—Sheet Steel Line Truck Body Fabricated by Arc Welding

By Fred S. Beach,
Designing engineer, operating department, The Northwestern Electric Co., Portland, Ore.

Preface.—The text of his paper will deal progressively with the description of the design and construction of the truck body proper followed by brief descriptions of the intended functions of the various parts of the body and the uses of attached equipment. This will be followed by a discussion of the investigation leading up to the formulation and the basis of the fundamental reasons for the design to meet the requirements of its operation and the efficiency of the unit. Following this the economics as applied to the company for which it was designed and made will be discussed and also as related to its economic possibilities applied to the entire utility field in the United States and finally a recapitulation.

This body design, (See Fig. 1), is based on a construction in which the cross members of the body rest directly upon the truck sill or frame

Fig. 1. Power company line truck arc welded at 20% cost saving.

channels depending upon the side wall construction for longitudinal strength without longitudinal body sills to form an independent body underframe.

The superstructure at the sides of the body is formed by a system of posts in two sets. One set extends vertically from their points of attachment at the ends of the cross members where they are arc welded with outside and inside continuous beads. From their junction

with the cross members to which they are welded, these posts extend vertically to a point 18¾″ below the top rail where the channel flanges are miter cut and the web bent over to form rafters which support the roofs over the spaces formed between the outer and inner post systems. At the miter cuts in the flanges of these outer posts, the section is bent over and is arc welded with full penetration butt welds; and where the rafter portion of outside posts joins the inside post, their ends are similarly butt welded also with continuous bead full penetration weld.

The other set of posts, designated by the symbols PI-1, PI-2, PI-3 and PI-4, (See Fig. 2), extends vertically from the cross members but are spaced 10¼″ inward from the outside faces of the outside set of posts. At each cross member the posts in this system are fitted and securely welded into the cross members by continuous bead arc welds. These posts are box section formed from sheet as channels with closure strips welded between the outer edges of the channel flanges with continuous bead arc welds for the full height of the posts. Posts PI-2 and PI-3 are of open channel cross section. From their junction with the cross members these posts extend vertically to the inside of the top rails and are arc welded with continuous beads, one bead at each of the free edges of the channel post flanges, along the flanges at top of cross members, down the post on each outer corner of channel posts inside the cross member and across the back of channel post inside the cross member. The box section posts are similarly welded with continuous bead arc welds inside the cross member and across at the base and across the width of the post at the cross member at each side. All four posts are welded inside the top rail.

After posts have been welded to top rail, soffit strips are fitted to the inside of the top rails in the spaces between adjacent posts. These soffit strips are arc welded with continuous beads along both flanges of the "U" section top rail. Between posts PI-1 and PI-2, beginning at the top of PI-1 and ending at the bottom of PI-2, and similarly between posts PI-3 and PI-4, are diagonal braces stiffened with struts between the diagonal braces and posts PI-1 and PI-4 respectively. This construction is seen in detail in Fig. 2.

At the outer ends of cross members are 16-gauge plates formed as channels with narrow flanges extending upward which form the bottoms of the lower row of material bins which, together with the rear wheel housing arch, combine to form the basic longitudinal strength members of the body construction. These bin bottoms and wheel housing arches are continuously welded where they join the cross members previously referred to.

The inside systems of body post diagonal braces, bin bottoms, inside and outside bin walls and tops and the top rails combine to form approximate trusses along the outside at right hand and left hand sides of the body.

Behind the rear axle, (See Fig. 2), drawer slide angles tack welded to these members accommodate two shallow tool drawers which slide below the underside of the floor of the bulk loading space. These drawers slide from either side of the body. They are intended for carrying flat

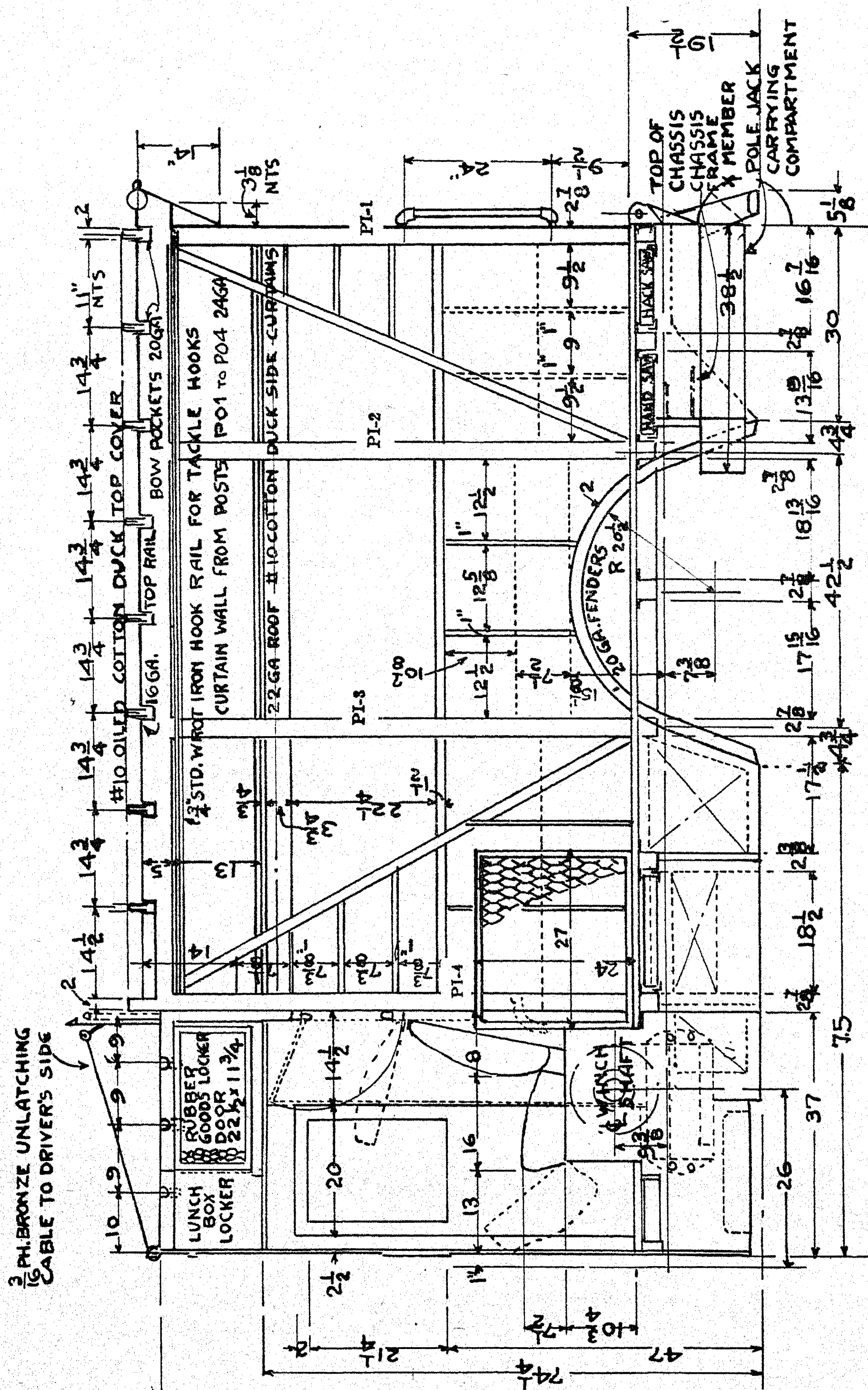

Fig. 2. Elevation view of power company line truck designed for arc welded construction.

tools, such as handsaws, one-man cross cut saws and small tools such as chisels, auger bits, stone drills, etc., which can be accommodated in drawers of this shallow depth. Another function of these drawers is for carrying standard rubber line hose.

Ahead of the rear axle is another shallow drawer but made wide enough to accommodate a two-man cross cut saw of five-foot length. It has the same depth as the two previously described drawers. While it is intended for carrying one complete saw with its handles mounted, additional saw blades may be carried if so desired. Reference to Fig. 3, shows the slots in the body side wall to accommodate the drawers just described.

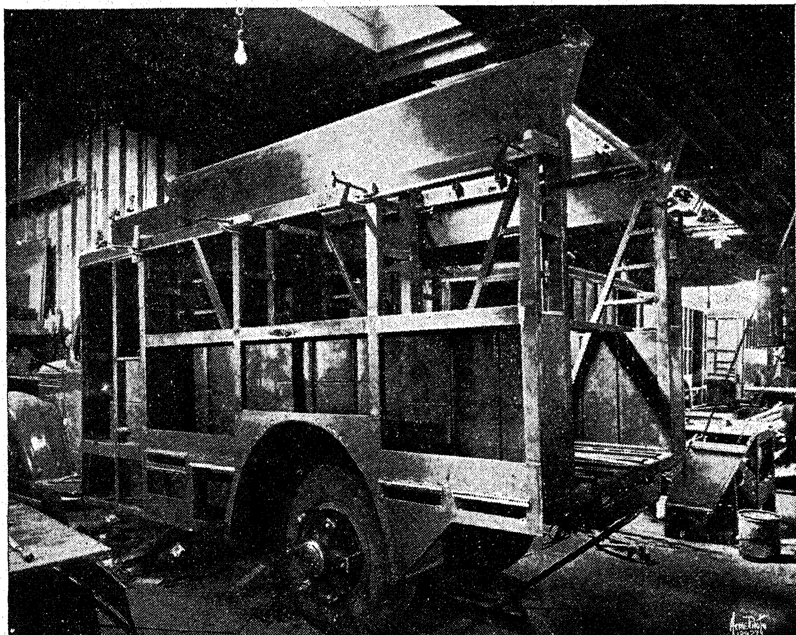

Fig. 3. View of line truck during fabrication.

At the ends of cross member No. 5 extending downward are divider posts of channel cross section shown in Fig. 2, marked DS-1, and similarly at cross member No. 6 extending downward are continuations of posts PO-4. Joined to these at their bottom ends, also at the forward tip of rear fender skirts and at the front cab wall, is a solid 16-gauge compartment bottom made in channel form 12¼″ wide. At the inside edge is a wall plate under and clearing the outboard bearing bracket of the truck winch terminating at the front wall line of the crew cab portion of the body. This makes a series of three stowage compartments below the body floor, winch and cab floors which are accessible through three doors.

The construction of the compartments, side walls and bottom form a structural tie between the front of the cab and the body proper where it

would be otherwise cut in two by the winch frame. The intention of this design is to make the winch accessible on occasion when major repairs are required on the winch. The seat riser and crew cab seat supports are made in such a manner that while assembled this portion of the cab together with bottom section of the division bulkhead between cab and body form a housing around the winch enclosing it. The seat riser is constructed so that it may be removed together with the seat cushion supports when repairs to the winch are necessary. The winch was mounted in the shop of the winch manufacturer before constructing the body.

Integral with the narrow edged roofs between outside and inside post systems, there is a wall panel extending from the roofs to the top rail. It is along the tops of the inside body posts and attached to them on the inside of the body by small formed angles spot welded to this thin wall plate and in turn arc welded to each one of the body posts and the diagonal braces. These wall panels extend from the front of the cab to the back end of the body. In the cab section this narrowing-in forms a clerestory in the cab. In this clerestory there are three compartments which are formed of No. 16 gauge x $1/2''$ mesh.

There are two compartments along right and left hand sides in this clerestory extending full length of the cab, $15\frac{1}{2}''$ wide on each side measured from the clerestory walls. Between these compartments at the front wall of the cab is the third compartment measuring 12" deep rearward from the front cab wall. This last compartment is intended for stowing the crews' lunch boxes while the first two mentioned are intended for carrying rubber goods. The bottoms of all three compartments coincide with the upper edges of the side roof ledges which extend over the cab section on a continuous line along the length of the entire body. All three of these compartments are provided with top hinged doors equipped with suitable fasteners to keep them closed. The system of stiffeners attached to the division bulkhead between cab and body simultaneously forms a support for the pole derrick to rest upon when the derrick is not in use and headers and sill for the crew cab back window. The diagonals in this system of bulkhead stiffeners intersect both systems of body posts and by their attachment to the bulkhead and the attachment of the bulkhead to the front body posts of both systems transmit a load caused by the weight of the pole derrick in its carrying position. This system of stiffeners and combination of pole derrick support were fabricated as a unit and set in place on the division bulkhead after it had been constructed and joined to the body posts themselves. It is tack welded at several points on the bulkhead itself and with continuous bead welds at the points where each set of posts is joined to the bulkhead.

The space over the material bins above their tops is divided into open sections by a small channel separator with two spaces for carrying cross arms and will accommodate eight cross arms each which have a cross section of $3\frac{1}{4}''$ x $4\frac{1}{4}''$ or four cross arms $3\frac{3}{4}''$ x $5\frac{3}{4}''$. Two other spaces above those mentioned are intended for carrying digging tools, tamping bars and similar equipment. Above the upper spaces covered by the narrow roofs, provisions are made to carry a fourteen foot extension ladder on the left hand side of the body and

on the right hand side a compartment, 7′6″ long beginning at the back end of the body is provided for carrying "hot line" tools. Outside of this along the edge of the right hand roof, racks are provided for carrying pike poles.

Anchorage of the body to chassis is by means of brackets attached to cross members. This method of anchoring the body to the chassis is considerably more rugged and safer than the method generally employed for attaching custom-built bodies to truck chasses. The principle reason is that in this form of attachment the holding bolt at each anchor is in shear and the whole combination has a minimum weight and stiffens cross members at their points of support on the chassis frame. The fastening bolts are all placed on a line of the neutral axis of the truck frame side channels. They do not have a tendency to weaken these frame members as the tension of typical double bolt or "U" bolt body anchorages would have due to the fact that the latter method of attaching bodies to truck frames puts the fastening bolts in tension and when this occurs, such bolts are liable to be drawn up tight enough to buckle the channel frame sills which would naturally weaken these members.

At the rear end, and bracketed out from the rear of the body top rail, there is a split bearing with a hinged cap held in place by a single stud and a forked lug, the latter being integral with the cap. The purpose of this split bearing is to provide support for the spindle shaft. On the inside faces of both body top rails is a series of bow pockets which receive the ends of the top bows carrying the canvas roof. There is a fixed top bow welded to the top edge of the separating bulkhead at the front of the body. Between this top bow and the forward side of the next adjacent bow pocket, on a line corresponding with the bottom line of all the bow pockets and extending inward from the inside face of the body top rail, is a shelf as wide as the top bow pocket extension from the inside of the top rail. The top bows are removable from their pockets and can be stacked into and carried by the shelf just described when it is desired to remove the canvas roof from the body. These bows are formed of No. 20 gauge material and after forming are cambered to have a 1⅞″ rise at the center.

Referring to Fig. 4, there will be a slight difference in the type of construction of the rear outside body cross member. This item is the heaviest single unit member of the whole body construction. It is formed of No. 10 sheet; and, inasmuch as two bodies only were under contract, it would have been uneconomical to build special die equipment for press-forming this member. Consequently it was laid out and the sheet trimmed to shape. Cuts were made where the lower flange inclines from the full depth at the center section to the outer ends. The forming was done by using a hydraulic wheel press for which power brake dies were made by the contractor's shop on other work preceding this construction. These power brake dies were used to bend the flanges both upper and lower. The upper flange is parallel to a section of the bottom flange which has a length of the approximate width of the truck chassis frame. The top flange is cut away at the bin sections of the body and extends in on the top surface of the loading space floor.

The two lugs which are welded at the center of this cross member are for the purpose of pinning the lower end of the pole derrick when it is set up for pole setting purposes. The two brackets at the ends of this cross member provide points for the attachment of the stiff leg jacks. Adjacent to each of these brackets are the two steps which are for the purpose of climbing from the ground into the truck loading space. The step hangers of these steps are brake-formed channels made from No. 12

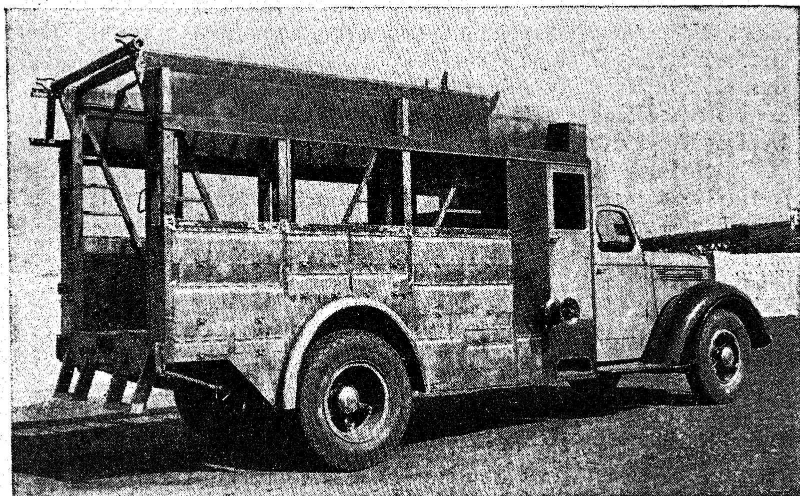

Fig. 4. Power line truck in advanced stage of construction.

gauge sheet. The step treads are made from a combination of an acute and an obtuse brake-formed angle and No. 9 x ¾" industrial mesh. This construction provides a safety step which has a non-skid surface and being constructed with the No. 9 industrial mesh, the steps are self-cleaning. This self-cleaning is for snow, slush, mud or other substance which would tend to make a solid step dangerous. Between the steps and centered on the horizontal center of the rear truck frame cross member are the tow coupling and safety chain loops. A fabricated No. 12 gauge sheet steel reinforcement, having a spring pocket built into it, was placed on the inside of the rear truck frame cross member and tie rods were installed, one on each side of the tow coupler draw bar extending back diagonally to the truck frame longitudinal sills at a point near the next truck frame cross member. These items, referring to the coupler and the reinforcement of the truck frame, are mentioned but form no part of the body.

The rear outside cross member is bolted securely to body cross member along the horizontal center line and at the ends by the bolts which hold the stiff leg brackets. There are bolts in the upper flange of this cross member which go down through the loading space floor boards and top flange of rear cross member. The outside rear cross member is also securely bolted to and through the rear truck frame cross member and its inside reinforcement described previously.

Referring to Fig. 5, there are five longitudinal members, one on the center line of the body and two on each side of the one along the center line which are called floor board separators. Along each side of the body, inside the bin walls, are longitudinal members terminating at the rear inside post extending to the rear side of the wheel housings; also beginning at the front side of the rear wheel housings and terminating at the front inside post PI-4 are marginal fillers. The floor board separators and

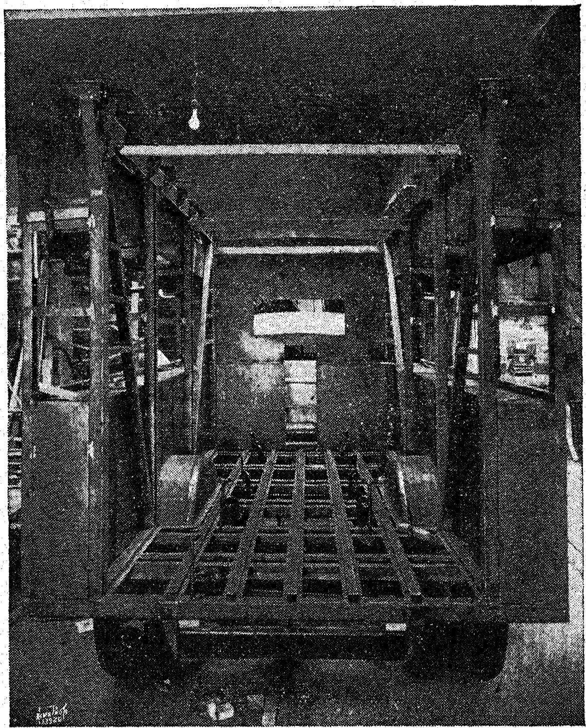

Fig. 5. Interior of truck showing details of frame.

marginal fillers are welded at each cross member and are for the purpose of supporting and positioning the six boards which make the floor of the loading space. The floor boards are laid between the separators and between the separators and marginal fillers and are held from moving lengthwise of the truck by the flange of the rear outside body cross member at the rear where it overlaps the floor. This construction adds stiffness to the body and makes the use of special bolts for holding the floor boards in place on the cross members unnecessary.

The floor boards themselves, together with the wooden floor in the cab and the oak cushion blocks, are the only pieces of wood used in the entire body construction. The loading space floor and cab floor are of selected spruce to assist the main object of this construction which is minimum weight.

The material bins on each side of the body are symmetrical with each other except that they, of course, are right and left handed. Between the inside bin wall stiffeners there are formed angle ledges which were spot welded to the inside bin walls because of their light weight gauge. The purpose of these ledge angles is to support the bin bottoms of the upper tier of bins. These bin bottoms are made of No. 16 3/4″ mesh. The vertical partitions separating the bins lengthwise are made with No. 16 x 1/2″ mesh.

The bin door locks, while decidedly unconventional, in typical line truck construction, contributed to considerable weight saving since these sash fasteners used as locks weigh approximately 4 oz. to the pair as against approximately 2 1/2 pounds to the typical line truck door bolts used by many of the power companies and the telephone companies for bin door closure. The weight saved by this procedure was approximately 72 pounds which is the difference between the weight of conventional bolts and the sash fasteners which we used. These sash fasteners list at $2.00 per dozen in our local hardware catalog whereas the line truck door bolts of conventional application list variously between $1.50 and $2.00 *each* and have a great many parts which are subject to breakage and require considerable repair when they are out of order. With the sash fasteners, however, at their low cost, when one of these gets out of order, it can be taken off and replaced quickly and at a minimum of expense.

In some of the newer line trucks constructed recently for other companies, the crew cab has been constructed with a single door for entrance and exit on the right hand side of the body only. This feature was our criticism of the various other designs examined in our investigation before undertaking our own design. Realizing that the unforeseen has a way of happening when least expected, we decided that if for any reason a truck was tipped over, the most usual side on which it would lie after being tipped over along a road would be the right hand side. The window in the crew cab on the left hand side did not afford as free escape from the tipped-over truck as a door exactly like the one on the right hand side. Our body was designed with doors on both right and left hand sides and both alike.

This truck unit is provided with a pole derrick which is a simple gin pole made of selected yellow fir, clear spar stock, and turned to the conventional curved taper, commonly used on ship spars. The upper end is slotted for the head sheave of the gin pole and a strap covers the sides of the upper end while in the sheave slot opening wearing plates at the pin hole for the sheave are provided. An anchorage is provided just below the sheave slot for the four guys which support the pole when it is raised. Referring to Fig. 1, the gin pole may be seen in the position in which it is carried while the truck is on the road.

The spindle shaft, as it is called, is used for several purposes, the principal one being for pulling old poles and guy anchor stubs out of the ground when replacements become necessary. The spindle shaft on this truck is equipped with two 8″ deep grooved semi-steel sheaves, one placed between the legs of the pole derrick gin pole support on the shaft and one at one side. When in use the winch line is passed over one or the other of these two sheaves and hitched to the pole or stub to be pulled out of the ground. When thus pulling either pole or stub, a suit-

able prop is placed between the shaft and the rear edge of loading space floor near the sheave. This helps to support the shaft and aids in resisting the heavy load imposed by such duty on the shaft.

The gin pole is supported at the rear of the truck for carrying only on the spindle shaft which is a secondary function of this shaft. When the pole is set up, the foot of the pole rests on the center of the loading space floor at its rear end where the load is taken. The load is transmitted to the ground through the heavy rear outside body cross member to the stiff legs. The pole is kept in its upright position through the agency of a system of four guys which can be clearly seen in Fig. 6. When it is desired to set up this derrick for raising poles, the line from the winch is passed through a snatch block anchored into the rear of the bed of the truck body. The line is passed up over the choker through the sheave and hooked into the base of the pole. The pole is released from the combined

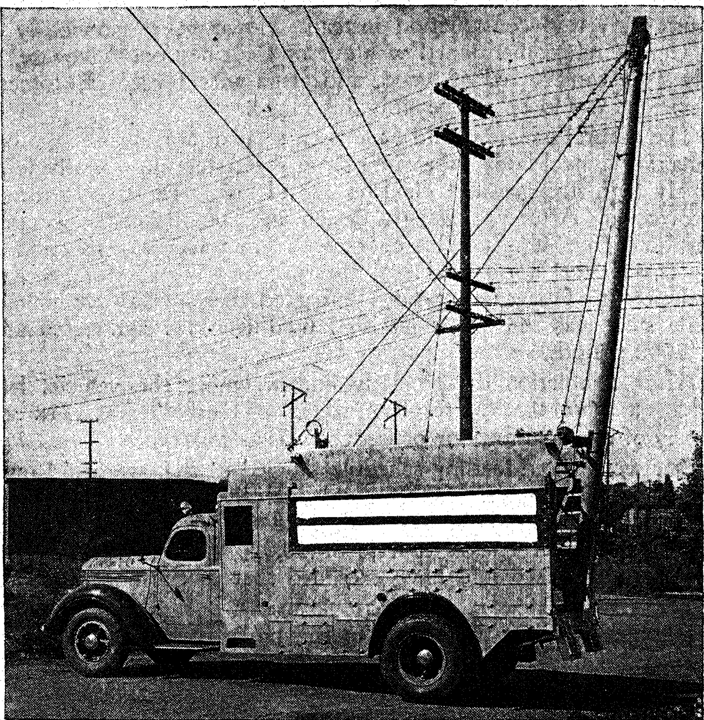

Fig. 6. Gin pole in position on completed truck.

rest and lock of the forward end of the body after which the winch is started and the pole pulled in and "stepped" onto the rear end of the body floor or bed.

Conclusion:—The principal problem in the design of this equipment was to obtain the most value for the least expenditure of cash which was accomplished without sacrifice to crew convenience, efficiency of the unit

or sturdiness in construction. In deciding the question of chassis capacity, preliminary study of tentative design based on the previous experience of the designer (who is also the author of this paper) in body building, coupled with investigation of stock body designs and those developed by other power companies, it was found that what had gone before and the results of the efforts by the commercial body builders and the results of the work of other companies in body development would produce heavier body weights than were desirable for the unit under construction. These heavier weights ranged between 2700 and 3000 pounds. Such body weights when combined with the weight of the equipment, tools, materials and crew would require the purchase of a chassis in the next heavier weight class than the one which was finally decided upon and purchased. It was certain that a body the size of this one could be built in steel fabricated from sheet and arc welded within the above weight range in simple open hearth steel with accompanying possibility of using rivetted construction instead. However, as previously stated the weight range mentioned was out of the question. Likewise, if the body were constructed of wood, and fitted with forged reinforcements, the weight would be far beyond this range.

The natural course would have been to avail ourselves of the benefits of making a steel body fabricated from sheet steel now available of extremely high strength and yield point and highly resistive to the effects of corrosion. After preparing a design and computing the weight of a body built from it using this character of material, our selection was a high tensile steel not available at the time of any previous body design development. Our computations indicated that a body in which high tensile steel was the major material used would weigh between 1800 and 2000 pounds.

After completion of the body and weighing the vehicle, less the ladder, we found that the resulting weight of the body was 1958 pounds. By way of explanation, our procedure was as follows:

Our weight and loading schedule showed us that we could purchase a chassis rated to weigh 15,000 pounds inclusive of body and equipment, fuel oil and water and the pay load. Had we been forced into the purchase of a heavier chassis or one of 20,000 gross loaded weight, our cost of the chassis would have exceeded that of the one purchased by $650.84.

The unit which is the subject of this paper was prepared for use in urban and rural line construction service in a neighboring state where the gross load rating is the basis of determining the cost of licensing trucks. For a truck weighing and rated at 15,000 gross, the annual fee in addition to the regular license fee of $3.00 is $18.00 but for a truck weighing 20,000 pounds gross the additional fee is $45.00 making a difference of $27.00 per year.

The company operating this truck follows a policy of using its trucks for a minimum of ten years. This term can be considered here as the useful life of the vehicle.

Considered on this practical life basis we compute interest at the rate of 6% a year for ten years on the cash saving of $650.84 and we find that the annual interest is $39.05 whereas for a ten-year period it is

$390.50 and the sum of principal and interest $1041.34. If we apply interest to the license saving at the same annual rate, the first year's savings would be computed and accumulated for ten years, similarly the second year's savings would be computed and accumulated for nine years and the third year for eight years and so on until the last year for one year. Computed by this method for ten years the interest on $27.00 per year for ten years would be $89.10 making the total of principal and interest $359.10 and adding the two gross items of $1041.34 and $359.10 shows a gross of $1400.44.

In addition to this saving which is one of the benefits resulting from the use of a body of this design, a comparison of cost of this unit and the one which it replaces and which was purchased and placed in service in 1928, the company's records show that this earlier unit cost $6439.00 and the new unit equipped with this latest body design shows a total invoiced cost of $3380.69 to which is added $600.00 as design and inspection cost making a total of $3980.69. The difference in the cost of the two is $2458.31. Neglecting the savings by the reduced license cost, (because of the differences in arriving at the license fee cost is strictly one of local state laws), we add the gross amount of cash savings in the purchase price of the chassis to the difference represented by the cost saving effected by this body design and we have $3449.60 as their sum. If interest is applied at the same rate to the cost difference item, a sum of $1474.98 should be added to this sum which would bring this to a gross amount of $4924.63 including all interest items as applied to the full useful life of the unit.

Substantiating the cost of this unit, the invoice cost detail is as follows:

Item	*Invoiced cost*	
Chassis	$1891.44	
Winch	375.00	(installed complete)
Body	1016.45	
Pole derrick	59.80	
Stiff legs	38.00	
Actual engineering time	600.00	(not invoiced)
Total	$3980.69	

Based on the invoice cost of $1016.45 and a scaled weight of 1958 pounds the unit cost of the body is 51.9c per pound. Had rivetted construction been employed, approximately 10% more weight would have been added to the weight obtained by using welded construction. Through inquiry it was learned that the local cost of rivetted structures in materials like those used in this body would be 20% higher than welding, which would make the unit cost per pound 62.28c per pound and if the scaled weight of the body were increased 200 pounds its weight would then be 2158 if rivetted construction were used. Multiplying this weight and the rivetted construction cost this body would then have cost $1344.00. This shows an excess cost difference of $327.55. This cost difference represents a saving of 32%. Considered on the same basis as the other savings referred to, namely, over the period of ten years' useful life, and adding 6% interest for ten years, we find that the interest would amount to $196.53 and adding this to the principal $327.55 we have a gross

amount of $524.08. With this amount added to the other gross savings, the final sum becomes $5508.69 (ten years' interest included) as applied to an assumed useful life of the unit of ten years.

Should the power industry of the United States generally adopt this design of body, or one very similar with modifications to make it suitable to requirements for local conditions, a gross saving amounting to well over $6,000,000 would result.

Now with the company's cost difference and apparent savings made by the adoption of the truck unit described, plus the interest on all items amounting to $5448.71 if multiplied by 1977 trucks, the total savings accruing to the country's utilities over the period of ten years predicted useful life of new light weight equipped trucks would amount to $10,890,669.06.

Chapter III—New Design of Side-Dump Semi-Trailer

By NELSON SEVERINGHAUS,
Superintendent, Consolidated Quarries Corp., Lithonia, Ga.

It has been but a few years since automotive haulage was introduced in quarries and mines for moving coarse material from loading point to processing equipment. Now it has been widely adopted with practically all new open pit operations so equipped and many older ones with tracks for locomotives and cars or hoist inclines being remodeled.

First installations used standard road haulage dump truck equipment as this was readily available. Gradually bodies were modified to withstand severe use and body types in use on track equipment were widely adapted to trucks.

Now there is a growing realization that this is a specialized transportation problem vastly different from the usual truck haulage and that the assemblage of truck and body units already on the market has not given the best possible solution. Until this is realized and proper equipment designed, little further progress can be made. Some of the factors which make this a unique problem are:

(1) The distance is generally short with the dump point fixed at the primary crusher.

(2) Large shovel dippers require large bodies for easy loading and avoidance of excessive spill.

(3) The quickly changing loading point makes for rough roads over at least part of the distance covered.

(4) Large size and abrasiveness of material often handled and the nature of power shovel loading make an extremely rugged carrier necessary to avoid excessive maintenance. Also a relatively large number of loads are handled per day.

(5) The fixed dump point offers the chance of quicker and cheaper discharge of body contents than that effected with conventional equipment.

(6) To avoid loss of time and cost of backing to the dump point, side dumping bodies have been widely used but most of them have been hard on the carrying chassis because of their high center of gravity and transfer of load to one side during dumping.

With these things in mind I have designed, and our company has built a new type semi-trailer haulage unit. It was designed for construction by electric welding of standard structural shapes and plates as such construction was considerably cheaper than other methods and did not require extensive shop equipment. Electric welding also gives a more rigid and rugged assembly, a characteristic all important in such rough work. Construction of this unit by any other method than electric welding would not have been feasible in our own shop as we do not have proper equipment to form and assemble such a large job.

Fig. 1 shows a picture of this unit on the road from quarry to crusher with an older type, direct mounted body behind it.

Fig. 2 shows the semi-trailer body being dumped by air hoist at the primary crusher. Note that most of the side dumping strain is transferred to a block supported from the ground and that practically none of the shifted weight is transmitted to the truck chassis.

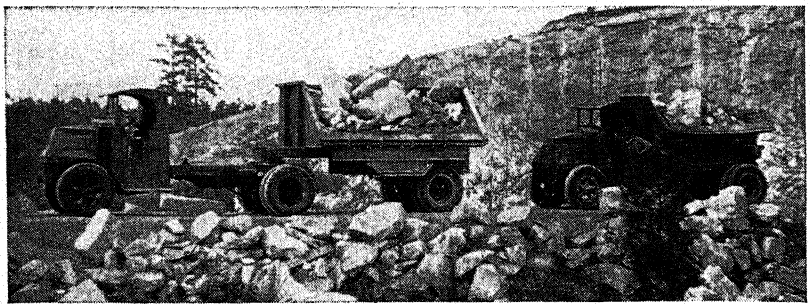

Fig. 1. Side dump semi-trailer with old-type at right.

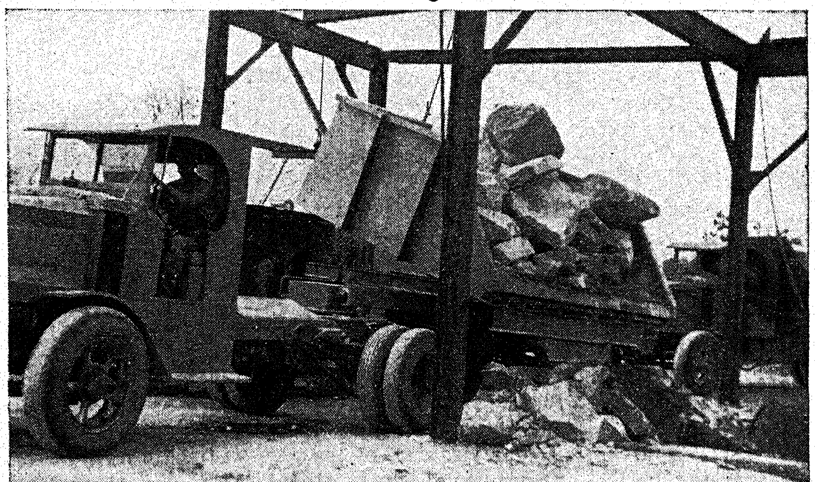

Fig. 2. Semi-trailer body being dumped.

The older type direct mounted body in Fig. 1 has both sides raised from the relatively narrow bottom at an angle of about 45°. It is hinged for side dumping with steel castings riveted to each end of frame and body. Its shape makes support during dumping difficult so none is provided. Thus, as an external hoist lifts the off side for dumping, a considerable load is transferred to the near side of truck chassis, resulting in frequent breakage of springs and frames. Complete external support of the new type body as shown in Fig. 2 eliminates this added strain.

Inverted trapezoid cross section of the old body gives a center of gravity considerably higher for the same load than the open side flat bottom construction of the new unit. A higher center of gravity increases strains to chassis in traveling over necessarily rough roads near quarry shovels.

It should be noted that the outer edges of the old type body must act as full length beams to support loads and although they are built heavily and helped some by bent I-beams carried across under the body, such units here have become "sway-backed" in use, concentrating weight at middle of under frame and sometimes breaking it. In the new type body, the high closed side is at right angles to the flat floor and welded securely to straight supporting I-beams resting on the frame and running full width. An I-beam which takes weight on the near side during dumping runs full length and aids in lengthwise rigidity. This box-like section should be considerably harder to bend and is certainly easier to construct.

The older unit is riveted throughout and the severe service to which it is put loosens rivets in time requiring a repair job which is difficult when some of the members have been bent. The new unit is largely welded with a few rivets used in holes found desirable for bolting members together during assembly by welding. This rigid welded construction should lower repairs on a body subject to constant shock and vibration.

Assembly and details of the new unit are shown in Figs. 3 and 4. In construction, the four cross I-beams and two cross channels which fasten to and brace the dump part, were first welded down on the 3/8″ body bottom plate with a continuous weld along both flanges. The sub-frame was then assembled as shown in Fig. 3 and fastened to the rear section of an old 5-ton chassis with welded fish-plates and braces. It will be noted that only a short section of the old chassis was used at the rear end to give a convenient wheel, axle and spring mounting and that the main frame of the semi-trailer is made by two 15″ channels which are part of the body sub-frame. To avoid weakening these channels with bolt or rivet holes, the five I-beams fastened to them were secured with bent clips welded on, as shown at bottom right, Fig. 4.

The assembled floor of the dump part was next turned over onto the frame and secured by a 2-inch diameter hinge pin running full length. Hard bushings with provision for lubrication were welded into the fixed beams and the hinge pin welded to the movable beams as shown at bottom right, Fig. 4.

To secure adequate fastening of the 10″ channel side braces, one side of the top flange of I-beams to which they fasten was removed for 10 inches and the braces welded all around to web and bottom flange.

Side and ends were next attached as shown in sketches marked "HIGH SIDE" and "END," Fig. 4, and the 3/8″ the bottom plate welded to them all around. To take the shock of large rocks sometimes weighing several tons and dropped from several feet from shovel dippers, a sandwich type floor was used with 2-inch oak boards between a one-half inch top plate and the three-eighths inch bottom plate. The top

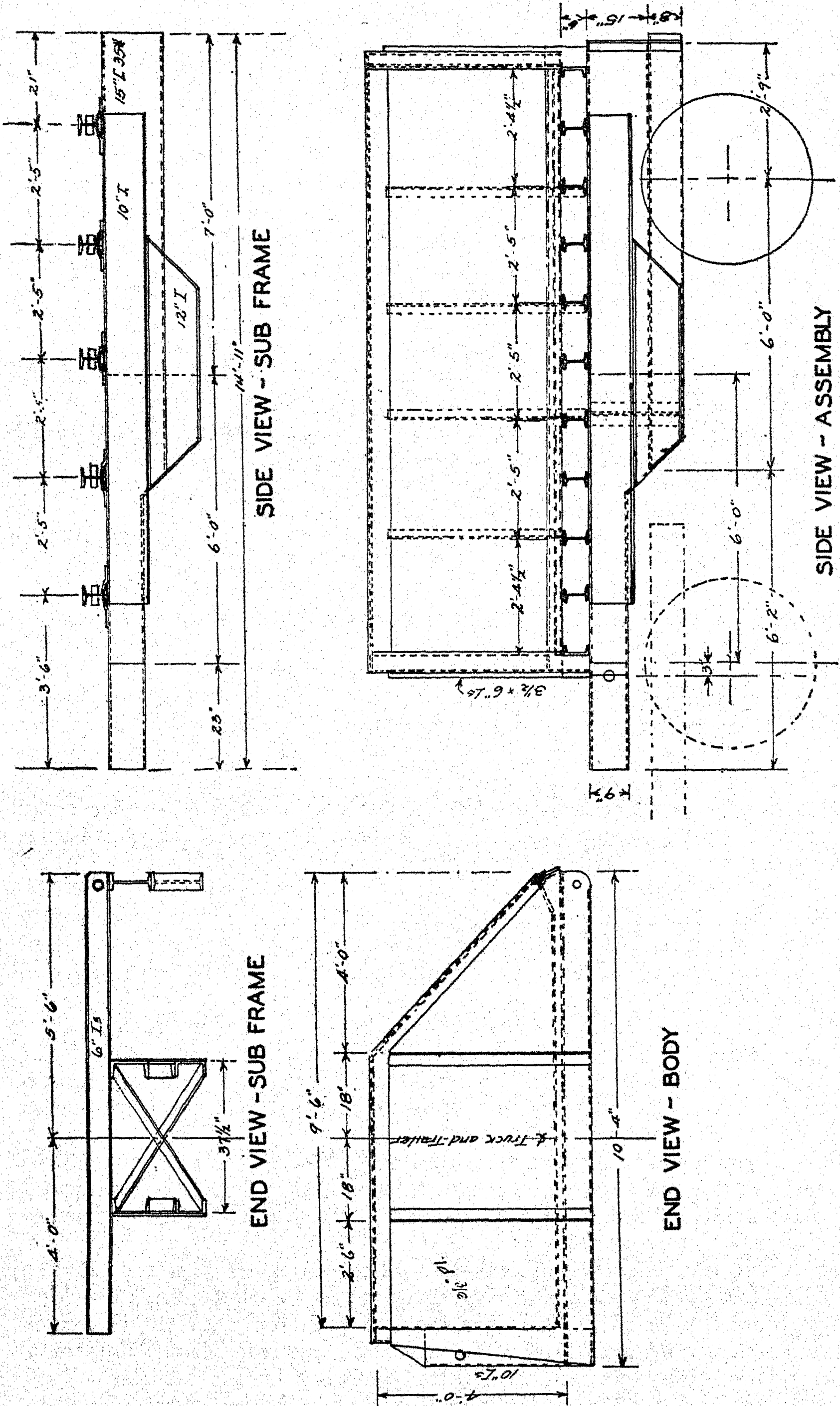

Fig. 3. Assembly of semi-trailer.

plate was also welded all around to side and ends as this helps greatly to keep these members from bending outwards.

On the open dump side, a 6″ × 8″ × ¾″ angle iron, placed as shown in sketch "OPEN SIDE," Fig. 4, forms a slight rise to prevent rocks from rolling out in transit. Because of the abrasiveness of rock handled, the top edge of this angle was given a welded overlay of manganese steel to take wear during dumping. This is shown in sketch "OPEN SIDE," Fig. 4. Two angles which are welded together and which reinforce the top edge of ends and side were cut out on their ends and bent to lap down over this 6″ × 8″ angle and welded to it securely. This helps to brace the ends when they take punishment during loading. The heavy dumping edge angle was also welded to the top floor plate for the full length of the body.

The fifth wheel too was constructed of plates and structural shapes welded together as shown in Fig. 4. It is considerably heavier than usual fifth wheels but it must be remembered that its duty is very severe.

The following tabulation shows cost and operating comparisons between this semi-trailer unit and a conventional eight-yard side dump riveted construction body. It has been found in practice that this eight-yard body is about as large as can be used on any ordinary truck for direct mounting. It has been widely used in the quarrying industry.

COMPARISON OF FIRST COST

	New Trailer Unit	Old Type Unit
First Cost	$1,388.29	$1,137.79
Avg. tons handled each trip	12.5	6.5
Cost per avg. ton handled	$ 111.06	$ 175.04
Saving per ton of capacity	36.5%	

Cost of the old type body, which was purchased from the manufacturer, comes from our records of invoices and freight bills. Costs of the semi-trailer unit is from our material and labor records and included steel for body and frame, tires, axle, wheels, springs and assembly labor and shop costs.

OPERATING COSTS

	New Trailer Unit	Old Type Unit
Tons handled per hour operation	77	40
Costs per hour operation:		
Driver	$0.385	$0.385
Gasoline	0.382	0.347
Lubricating oil	0.055	0.055
Tires	0.272	0.245
Repairs	0.435	0.435
TOTAL COST PER HOUR	$1.529	$1.467
Cost per ton handled	1.99¢	3.66¢
Cost saving per ton handled	1.67¢	
Percentage saving in operating cost	45.7%	

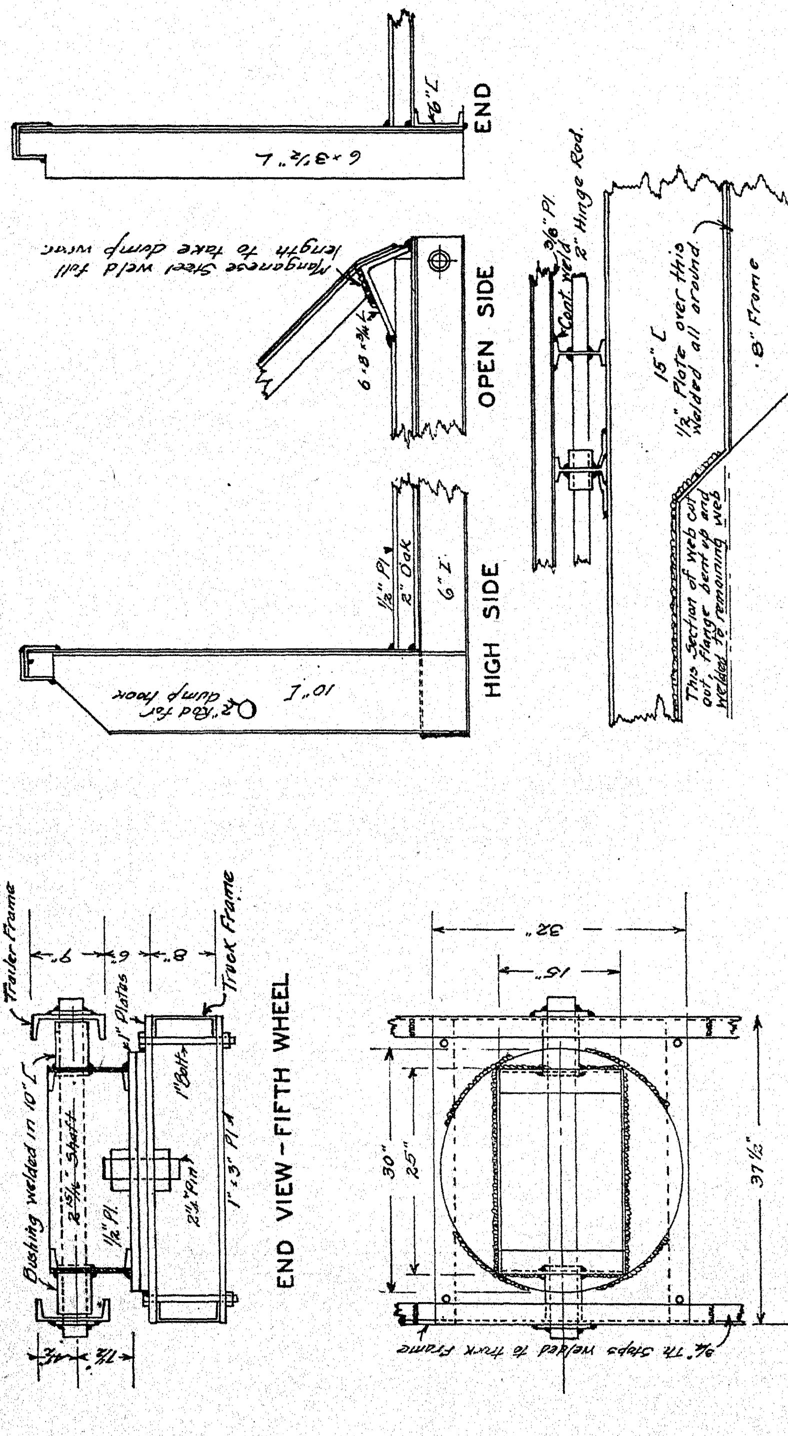

Fig. 4. Details of side-dump semi-trailer.

In figuring the gross savings which would accrue to the quarrying industry through the general adoption of this new type haulage unit, it is necessary to estimate the percentage of tonnage which could be handled by this type unit. Minerals Yearbook—1937—published by the U. S. Department of the Interior, Bureau of Mines, gives the total tonnage of crushed stone sold or used by producers in the United States in 1936 at 156,793,000 tons. From observation of the plants in this territory it seems quite fair to assume that at least one-half of this, or 78,397,000 tons is at present handled by trucks and bodies which on the average are no better adapted to their work than the original haulage units here. Thus, when this quarry shows an operating saving of 1.67¢ per ton handled, the same or greater saving should be practical in the handling of about 78-million tons annually in the industry or a gross saving of about $1,303,000 per year.

Because of its simpler construction with full support of the flat floor, it is believed that the new type unit should give longer service with less maintenance than the previous type units. In practice here, it has been necessary to completely replace one body for about each 500,000 tons handled. Again assuming this figure should apply to the industry as a whole, about $177,000 worth of bodies must be replaced annually. Figures show a further annual saving here of $65,000 in replacement costs without counting on any longer life.

We have not yet had enough experience with the new type unit to accurately compare maintenance costs but a study of design of the two units indicates a longer life with less repairs for the new type. This should apply to the trucks as well as body, since most of the strain on chassis in rough traveling and dumping has been removed.

SUMMARY

(1) A new type, welded, side-dump, semi-trailer quarry haulage unit has been designed, built and put in use.

(2) Its general adoption by the quarrying industry where applicable should show a gross saving of at least $1,368,000 annually.

(3) It is of simpler and more rugged construction than units in common use for this type of work. Electric welding made possible its assembly in a small shop and should add greatly to its usefulness and life.

Chapter IV—A Refuse Collection Vehicle Body

By HARRY WUNSCH,
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In collecting and transporting refuse in cities, it is essential that a large payload per truck be available to avoid frequent trips to incinerator or dump. The material is, as a rule, comparatively loose and bulky. To get the maximum operating efficiency with a modern heavy duty motor truck it is very desirable that this material be compacted to increase its density. With this as a basic thought, the body to be described was built and many other desirable characteristics also obtained.

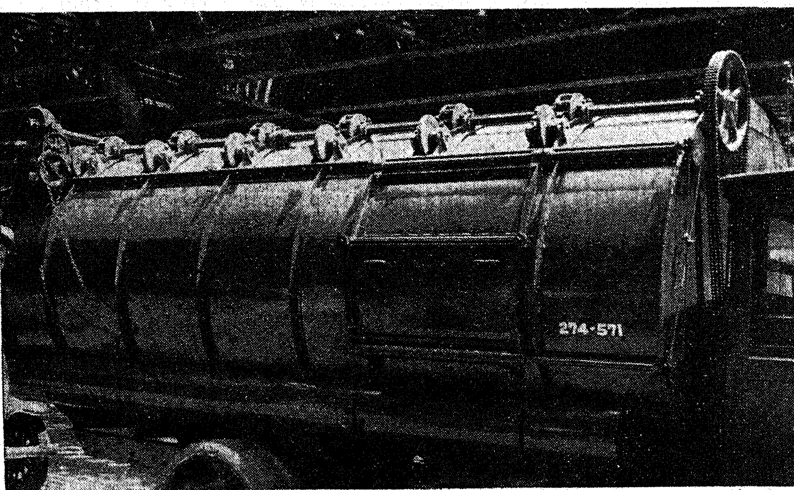

Fig. 1. Arc welded compressor type refuse collection body.

The body itself, Fig. 1, consists of a cylindrical tank within which is an impeller. The impeller is used to compact the material to a half or a third of its usual volume, varying with the refuse being handled, at a pressure of about 800 pounds per square foot. This impeller is also used as means of emptying the body. The impeller has, on its rim, gear teeth which mesh a series of pinions on a common shaft outside the tank. The pinion teeth protrude through openings into the tank. The impeller teeth are parallel to the cylinder elements, but they follow each other along a spiral form whose pitch is equal to the spacing between the outside driving pinions on their common shaft. Alongside the edge of these teeth is a groove on the impeller also following this spiral form. Engaging into this groove is a series of rollers fastened

to the body. These rollers support the impeller and take its thrust load when packing or dumping. The impeller is, therefore, capable of rotating within and moving lengthwise in the tank and at the same time is firmly supported to take large thrust loads.

Power is brought to the impeller from the truck engine by means of a reversing power-take-off which is part of the truck transmission. Knockouts are provided to automatically push the power-take-off into neutral at the limits of impeller travel. A knockout also snaps the power-take-off into neutral when a predetermined pressure is reached by the impeller when packing. A dashboard control renders this pressure knockout inoperative when the impeller is set in motion for dumping, so that a pressure greater than that used for compression is available for dumping.

At the forward end, and on each side of the body, is a loading door. This is a double wing, horizontally hinged door, with positive latches to hold it shut and capable of being opened and shut with unusual ease and rapidity.

The refuse is dumped into the door opening until it is well filled. The doors are then shut and the material pushed back out of the way with the impeller. This operation is repeated 7 to 10 times until the body is fully loaded. The total time required for these compressions does not exceed 20 minutes.

When ready to dump, the tailgate latches are released permitting the tailgate to swing free of the body. As the load is forced out, the tailgate is free to swing upward.

Rigorous tests of the body were carried out in two large cities, with all types and combinations of refuse materials. It is not necessary for this paper to detail the statistical results obtained. They were very favorable. The principle of operation was definitely proved and no commercially impractical mechanism or structure is required to carry out these principles. The advantages of this body may then be summarized:

(a) Unusually large payload capacity.
(b) Refuse is completely enclosed with only 2 loading doors.
(c) No lift required for body to dump load, so that:
  (1) Incinerator head room may be low;
  (2) No danger in striking overhead obstructions;
  (3) Body overhang will not strike ground obstructions;
  (4) No danger of overturning trucks with poor stability apt to exist at dumps;
  (5) Hydraulic lift system is eliminated;
  (6) Body is rigidly fastened to, and becomes part of, the truck chassis frame;
  (7) No abuse of truck frame due to twisting of an elevated loaded body on irregular ground;
  (8) Body dumps clean without "jockeying" and further abuse of the truck.
(d) Men do not have to stand in or above refuse, so that:
  (1) A definite hazard is eliminated;
  (2) A chauffeur and two loaders make an efficient crew.
(e) The curve at the bottom of the body permits the use of wide

running boards, so that the men may stand high in relation to the loading doors.

(f) Impeller motion crushes and compresses refuse so that:
   (1) No time is taken out to crush boxes;
   (2) Danger and abuse in the practice of crushing material under truck wheels is eliminated;
   (3) No voids in the loaded material.

(g) The impeller maintains its proper position because it is rigidly supported direct from the body throughout its length of travel.

(h) The nature of the crushing and unloading mechanism is such that all parts may be made simple and rugged.

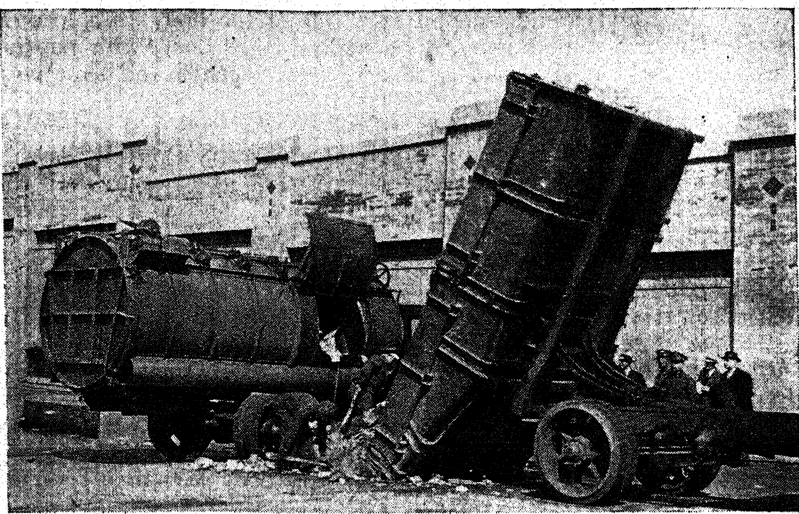

Fig. 2. Overflow load on open-type body is only two-thirds load for compressor type unit.

Fig. 2 shows a direct comparative test of this body with a large open body where the load was distributed by a man riding in the refuse. The load which filled the open body to overflowing occupied only two-thirds of the space in the compressor type body.

This body is in all major parts an arc welded structure. It is not commercially feasible to build such a mechanism in any other way now recognized, due to practical limitations of cost of fabrication and weight. There are on this body many levers, brackets, hinges and other details of arc welded construction. These were made up of stock rolled sections. In addition to reliability of the rolled sections and the saving of much machine work by eliminating castings there was no delay in founding. Pattern charges were also eliminated and these are always a large item when a single machine is built. Such parts do not present any modern novelty and will not be further considered. A more detailed study will be made of the four major body parts: The body cylinder or tank, the impeller, the loading doors and the tailgate.

The cylinder is a tank of $\frac{3}{16}$-inch plate, 6 feet in diameter, 15 feet long, open at one end and reinforced with rolled sections at regular intervals and around the openings. This was actually made of 3 pieces of plate, rolled up, welded longitudinally and then circumferentially.

It is difficult to make a direct comparison of costs on such a unit between the welded design shown and an unfamiliar design of riveted construction. The welded design was relatively straight-forward and withstood the stresses in a satisfactory manner; the detailing of this unit for rivets is full of unknowns as to labor involved and final performance. It will be assumed that the cutting, rolling and forging of the major tank parts will be the same for the riveted as for the welded design. Assuming further that the cost of electricity and welding rods is roughly balanced by that for punching, drilling and riveting power and rivets, a simple comparison of labor between the two joining methods will be made.

The butt welds in the $\frac{3}{16}$-inch plates were made by direct pentration of a shielded arc without veeing. The total of all welds is about 450 feet practically all of which is of $\frac{1}{4}$-inch bead. Welds were peened and wire brushed. Time for placing of all finished welding is about 30 hours for one man. No time will be taken for set-up, shifting and clamping with helper's assistance, as this will be about the same for welding as for riveting.

Equivalent riveting on the butt joints requires a splice plate with two rows of $\frac{3}{8}''$ rivets, countersunk and chipped smooth on the one head on the tank interior with a pitch of about 5 to the foot. Holes could be punched only in the splice plates and then transferred by drilling in place to the large tank members. The assumption will be made that punching will not cause sufficient damage to adjoining metal to result in cracking under the irregular strains caused by the working of the body. About 2300 rivets will be required of which about 2000 will need to have one side flush and smooth. Riveting requires a man and a helper. At least 250 man hours of labor for the finished riveting operation alone is required.

In addition to the extra time required for riveting, about 600 pounds of steel is added in the form of splice and reinforcing plates, and in the use of stiffener angles where welded flats would be satisfactory. This additional labor and material for riveting is necessary in addition to an unquestioned loss of rigidity. There would also be a definite weakening of the shell due to loss of section with undoubted eventual cracking through rivet holes. Without welding, the entire job becomes impractical and it is not conceivable that anyone would seriously attempt to build this part of riveted or bolted construction.

It is a pertinent question whether a thinner shell could not have been used of higher strength steel than common rolled plate. However, one of the major requirements of this cylinder was to keep the mechanism lined up and not to spring seriously out of shape when pressure is applied with the impeller. The high tensile steel has the same elastic modulus as steel of lower strength. If the section were made thinner, then it will be less rigid and no weight saving should be so attempted.

There is a drip tank at the forward end of the body. This was intended to catch fluids drained from the bulk of the refuse. Different cities have different practices in mixing collected materials. Some carefully segregate garbage, rubbish and ashes. Others mix them in any combination. It was found that only when an unusual load of high fluid content, such as might be picked up at a vegetable market, was handled by itself, that is without mixing miscellaneous rubbish with it, was there any appreciable amount of free fluid. Generally speaking then, this tank is unnecessary.

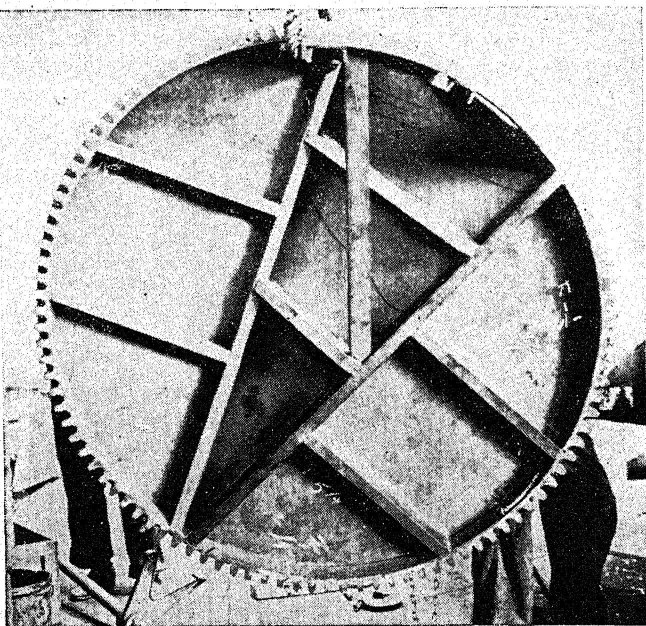

Fig. 3. Supporting structure at rear of impeller.

The assembly of the original impeller is shown in Fig. 3. The rim of the impeller consists of 6 cast steel rim segments having the gear teeth and spiral groove previously mentioned and a suitable surface to which to weld plates and shapes for the working face. Each of the six segments is somewhat more than 60 degrees so that the complete unit represents more than one complete revolution of the helix. This is necessary so that a complete engagement of the oncoming pinion may be made before leaving off the previous pinion. To facilitate this engagement of 2 pinions at the same time, the teeth in the first and last segments were made more pointed than the others. This gave a little more backlash to provide clearance for taking up irregularities and prevent jamming when 2 pinions are engaged at once.

In order to hold the rim segments to a spiral form, a welding fixture was made. This consisted of 2 semi-circular plates spaced parallel about 2 feet apart and connected with bars. These spacer bars were in a circular group such that the segments would rest on them at the

proper radius. Lengthwise along the bars were collars up against which one edge of the impeller segment could be clamped and thus held at the proper helix angle. A structural steel frame work was provided to support the completely welded rim and to carry the plates for the working face.

If it had been necessary to resort to bolts or rivets, the details of the joints would have been commercailly impractical to follow the contours of the warped surfaces involved to say nothing of the loss of rigidity.

The center plate which connected the two extreme ends of the spiral was rather sharply inclined to the general face of the impeller. It was soon found that this surface was picking up the material and moving it round and round. This required extra power and because of the irregular pressure created a rumbling. Another piece of plate was formed to match up with the leading edge of the offending part and across to the rim. Thus another face presenting a flatter surface was quickly and easily welded on. This worked very well. In operation the face of the impeller crushes and rolls the material as it goes around, filling up the voids. The welded surface, without protruding bolt or rivet heads, takes on a polish. The $\frac{3}{16}$-inch plate surface would have been difficult to hold in place with countersunk bolts or rivets. The design and construction of the rim joints would be almost impossible without arc welding. The use of countersunk screws to hold the thin plate onto the casting and subjected to severe localized stresses is an impractical solution.

To have made this impeller of a steel casting would have necessitated greater thicknesses adding at least 25 percent to the weight. To make such a casting requires a rate of about 10 cents per pound, against less than 4 cents for rolled steel from the warehouse. The cost of the steel as a casting would then be about three times that of a rolled and arc welded unit. The pattern alone, made of wood, would be worth $250 and is many times the cost of labor involved in assembling the welded impeller. No doubt irregular and unpredictable shrinkage in a casting would necessitate considerable machining. It is therefore apparent that a cast impeller is not to be considered over a welded one.

The tailgate must resist the pressure of the impeller when packing. It is held in place by wedging down into four heavy welded steel hooks, on the shell. It was originally intended to lift the tailgate free of its latches and swing it out by power. This was actually accomplished by means of a clutch connecting the worm drive to the impeller drive shaft. In view of the infrequency of operation and the fact that once the tailgate was free of its latches the load being forced out would swing the gate as far open as necessary, it was decided to eliminate the complication involved in a power lift. The hand chain to the worm drive has been used.

On the latest design, the relatively heavy worm drive has been eliminated in favor of a simple screw mechanism to lift the gate free of its latches. It is hinged in such a way that it will automatically swing up as the load is ejected. This also eliminates much heavy construction for lifting the tailgate as a cantilever.

Sufficient welding was used to develop the full strength of the com-

bined members, to hold the door flat and the entire unit stiff enough to keep its shape. The innersection had to be smooth in order to lift straight up out of the latches. The joint between the door and the shell is sealed with a soft rubber gasket. It would have been difficult to countersink rivets in the plate only $\frac{3}{16}$-inch thick and still develop sufficient shear to make the members act together. The joints between the cross members and the outer rim which carried the load into the latches would have had to be very complex and heavy if any method other than arc welding were used. Excess weight in the tailgate is at a double disadvantage because it not only is expensive and constitutes non-pay load but it adds to the cost of fabricating the releasing and locking mechanism. A single unit casting is out of the question because of excess weight, high cost of material, pattern cost and expensive machining.

The original loading door is shown in Fig. 2. The body opening was made to suit this door. It was soon found that the opening was unnecessarily large. This reduced the volume of compressed material available and increased the frequency of compression because of shallow loading space. A piece of $\frac{3}{16}$-inch plate was cut to the proper shape, rolled and butt welded into position to become a part integral with the original cylinder.

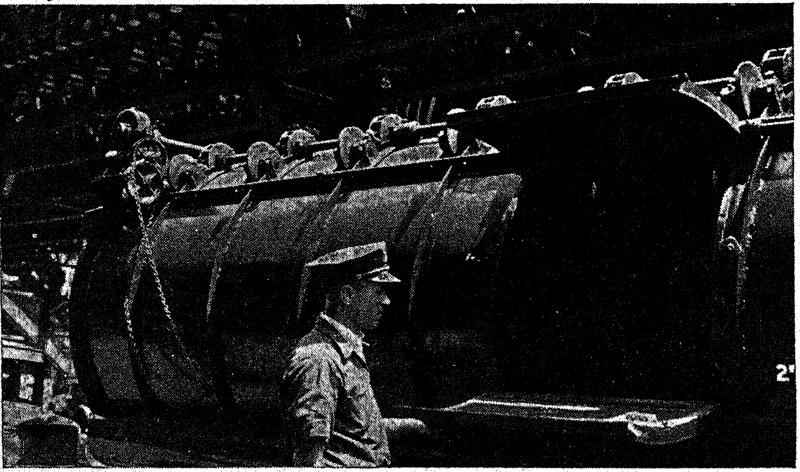

Fig. 4. Simpler door which replaced that used originally.

But the door itself was inefficient in operation and required an expensive cranking mechanism. It was removed and the door shown in Fig. 4 was substituted. This is a double leaf door with the halves so tied together that they counterbalance each other perfectly. No opening mechanism is required. Clearances around the body to open the door are small. A simple spring latch holds the door open so that it does not flap when traveling. A screw knob keeps it tightly shut against all internal pressure. On the new layout, a hinged arm latch will be even faster to operate. The lower sill has a heavy rub-

ber edge so that a can may be rapped without noise or damage. All hinges and brackets were built by arc welding of rolled steel.

A discussion of the loading doors would be incomplete if the great ease in modification of design due to arc welding were not pointed out. An alternative method of fabrication involving the use of rivets shows figures overwhelmingly in favor of the welded job in economy of material and labor for work on single units or in regular production.

The type of drive from the truck power-take-off to the impeller pinions' shaft has been changed. On the first body built, the simplest drive to connect the parallel shafts involved was a multiple width roller chain shown in Fig. 1. As a matter of fact it has worked with entire satisfaction. No breakage has occurred and beyond an occasional adjustment of the tightening idler has required no attention. It is however exposed to the elements and is not considered a good application for long service. The drive as it is intended to be made has the lower box carrying bevel gears connected by universal joints to the power-take-off. It also has geared limit switches for impeller travel and pressure cut outs. Connected to this control box by means of a vertical universal joint drive shaft is a worm gear unit that drives the final pinion shaft. These two gear boxes are within the body cylinder and are easily accessible by moving the impeller to the rear.

If the contemplated return to electric trucks for refuse collection in large cities materializes, the body described is well adapted to accompany them. Such elements as overload trips, limit switches, etc., can be accomplished even more simply electrically than they have been mechanically. The impeller will have its own driving motor with power brought to it from the truck batteries. The amperage consumption at the peak of compression may be high. This load however exists only momentarily and the total ampere-hour consumption for a day's operation of the body is very small compared to the requirements of the vehicle itself.

The body has been carried through the technical stages of its development. It is now ready for commercial exploitation.

Chapter V—New Bus Bodies by Welding

By R. S. Rose,
Chief engineer, Wentworth & Irwin, Inc., Portland, Ore.

During the past ten years, there has been a very rapid change in the method of construction and materials used in building bus bodies. Much of the earlier wooden construction has been changed to alloy steel and aluminum alloy during this decade of progress. Vast improvements in construction methods, most notable of which is the increased application of arc welding, have made this possible.

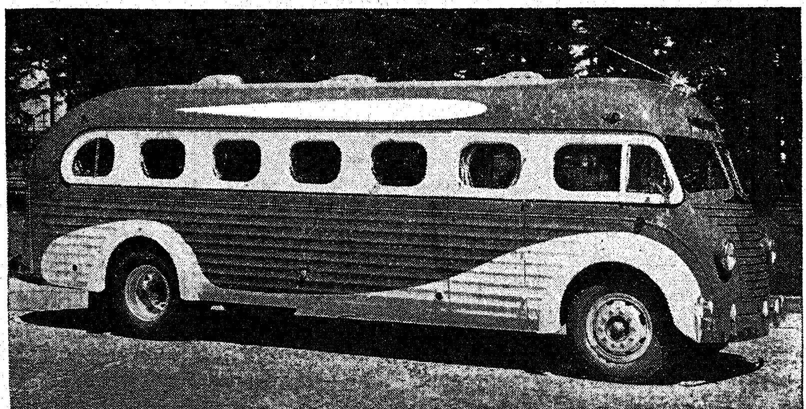

Fig. 1. Arc welding makes this modern bus possible.

Transition was first made from the composite type of construction during 1928, at which time the first two all steel bodies in the United States were produced.

One of the earlier problems was the lack of definite knowledge concerning the best method of construction to be used in these first all steel bodies. Arc welding, then a considerably smaller industry, appeared to be the solution to a quick, economical, and practical way to assemble the frames of these bodies. It was during this stage of infancy that the bus building industry took as its chief aid in construction the electric arc welder. The first arc welders used were a far cry from the modern efficient welders of the present day, but they served a purpose, that of establishing a method of construction which is today, with modifications, the same as it was then.

It is the purpose of this paper not to establish a new method of construction but rather to point out changes in materials necessary because the ultimate had been reached in the type of construction used

during the past decade. Inroads of private automobile transportation have made it necessary for the various bus companies to materially reduce their fares. Because of this decrease in fare, it was imperative that operating costs be reduced to a minimum in order that a profit could be made. Reduction in these operating costs could only be achieved by eliminating the dead weight in the vehicles then operating, through the media of lighter unladen vehicle weight. This paper is concerned with the latter subject.

The problem of selecting some better and lighter method of building bus bodies had best be approached by reviewing some of the features of the first all steel bodies which replaced the older type of composite body. The framework was constructed of various structural steel shapes and pressed steel shapes tied together by means of riveting and arc welding. Because of the lack of knowledge of actual operating efficiency of these all steel bodies, many of the component parts were oversized. Actual stress analyses, although run on this type of body, were inadequate to solved the complicated inter-tied structure, and in lieu of sufficient test data, component members were usually oversized rather than undersized. Gradually, through the ensuing years, added information on the performance of these bodies made it possible to reduce the size of a great many component parts without sacrificing structural strength, and as a result during the years 1935 and 1936 the weight per passenger had been reduced to approximately 485 pounds for the unladen bus. At this time it was realized that about all the weight had been taken out of these steel bodies that was possible. Therefore, new materials had to be incorporated in the construction in order to achieve any further weight reduction.

Our company had been doing considerable experimenting along several possible lines for saving weight. From these experiments there came to light several different avenues of approach namely, the substitution of light weight high strength aluminum alloys for all steel parts except those which were severely stressed: substitution of the then newly introduced mild alloy steels for the mild steel in the framing members and in the paneling: or the construction of a body with the best features of both of these methods. Being unable to discover anyone who had experience in the combination of the above two methods, it was decided to construct an experimental job using one of these mild alloy steels for the important framing members and paneling, mild steel being used only in places where severe forming made it inadvisable to use this higher strength steel. Considerable success was met with the construction of this project, but in order to get the complete story on light weight construction, it was decided to build an all-aluminum integral type experimental job. This job was not a bus but a dual axle semi-trailer. However, factors which we wanted were obtainable by comparing this job with previous semi-trailers constructed.

A careful study was made of the results of these experiments and the facts concerning bus construction plotted as shown in Table "A".

TABLE "A"

Item	Conventional Steel	Alloy Steel Aluminum	Alloy Aluminum
Total Weight	6450	4725	4220
Frame Weight	2480	1660	1220
Weight Saving	-------	1725	2230
Added Cost	-------	$255	$825
Cost per lb. Saved	-------	$000.15	$000.27

The fact that all-aluminum construction costs almost twice as much per pound saved, coupled with the fact that the alloy steel frame will stand twist, vibration, and strain considerably better, gives the alloy steel frame greater preference. Another factor favoring the selection of the alloy steel frame is that the net cost per pound of weight saved for the aluminum frame is too high as shown by the figures in Table A. Another very important issue or deciding factor favoring the selection of the alloy steel frame in preference to the aluminum alloy frame was the fact that, in the former, arc welding integrally tied together the various component structural members with a material equally as strong as the parent metal, thus obtaining a joint of almost 100 per cent efficiency. In the case of the aluminum frame, however, the efficiency of the riveted joints is considerably lower and the natural inability of the riveted structure to return to its original shape after deflection makes it necessary to pay particular attention to exterior paneling. In comparison, the alloy steel framework is in a sense an integral unit acting under stress as a unit and providing a much firmer foundation for the exterior paneling.

Having thus decided upon a suitable method of construction to be used, it was necessary to calculate the actual saving in operating costs which could be achieved. Table "B" illustrates such savings. Table "C" indicates the actual weight breakdown of these two different types of bodies.

TABLE "B"

Weight Calculations

Alloy Steel & Aluminum Body		Conventional All Steel Body	
Body Wt.	4725	Body Wt.	6450
Chassis Wt.	7925	Chassis Wt.	8000
Unladen V.W.	12650	Unladen V.W.	14450
24 Pass.	3600	25 Pass.	3750
Driver	175	Driver	175
Bag. & Express	1000	Bag. & Express	1000
Parcels	500	Parcels	500
Gas & Oil	500	Gas & Oil	550
Gross V.W.	18425	Gross V.W.	20425

Actual Weight Difference 2000 Lbs.

Rolling resistance of the vehicle at 40 mph on average concrete pavement is 16 lbs. per 1000 lbs. of gross vehicle weight.

$$\frac{18425 \times 16}{1000} = 295 \text{ Lbs.}$$

Air Resistance*

AR = 0.0013 (MPH^2 x A)

AR = 0.0013 (40^2 x 63)

AR = 131 lbs.

Total Resistance=AR plus RR

Power Required

$$HP = \frac{V \times R}{550 \times E} \quad \begin{array}{l} V = \text{Velocity} \\ R = \text{Res.} \\ E = \text{Eff.} \end{array}$$

$$HP = \frac{58.6 \times 426}{550 \times .85}$$

HP = 53½

Power costs \$0.015/HP hour

Average 100,000 miles/year @ 35 MPH or 2900 Hrs.

Cost=53½ x .015 x 2900 =\$2330

$$\frac{20425 \times 16}{1000} = 328 \text{ Lbs.}$$

Air Resistance

AR = 0.0013 (40^2 x 70)

AR = 168 lbs.

Total Resistance=AR plus RR

$$HP = \frac{V \times R}{550 \times E}$$

$$HP = \frac{58.6 \times 496}{550 \times .85}$$

HP = 62

Power costs \$0.015/HP hour

Cost=62 x .015 x 2900 =\$2700

Actual difference in cost is \$370 per year on level ground which is even more increased with grades included. This difference times the number of years the equipment is run amounts to a considerable saving. It should be born in mind that the actual decrease in maintenance, tire wear, and depreciation is less with the reduced gross weight.

*This data from experiments done by author.

TABLE "C"

Weight Comparison of Conventional All-Steel Body and Light Weight Alloy Steel Body

ITEM	Conventional All-Steel		Alloy Steel & Aluminum	
	Material	Weight, lbs.	Material	Weight, lbs.
Seats	Upholstery	920	Upholstery	800
I.S. Lower Lining	Masonite	75	Masonite	75
Glass	Plate & Sheet	220	Safety glass	205
Gas tanks and bkts.	Steel	85	Steel	60
Floor	13/16x6 fir	275	5/8 plywood	189
Floor Fillers	Wood	25	Wood	25
Heaters & Pipes	Copper tube	150	Copper tube	135
Insulation	....	....	Glass wool	105
Tire carrier	O.S. Steel	25	L.S. Steel	18
Trimming Mat.	Upholstery	40	Upholstery	40
Floor covering	Linoleum	120	Linoleum	115
Main body frame	Mild steel	1830	Alloy steel	1225
Front end frame	Mild steel	650	Alloy steel	435
Paneling O.S.	Sheet steel	900	Aluminum alloy	430
Paneling L.S.	Sheet steel	310	Aluminum alloy	130
Parcel racks	Steel & plywood	210	Alloy steel	150
Motor hood	Steel	90	Aluminum alloy	50
L.S. Bag. Comp. panel	Steel	175	Aluminum alloy	88
Bag. Comp. grating	Wood	....	Wood	85
Misc. fittings	Misc.	350	Misc.	365
Totals............	....	6450	....	4725

Actual weight difference—1725 Lbs. or 37½%.

Actual difference in frame weight—820 Lbs. or 30%.

Type of bodies compared are 25-passenger intercity types having the latest passenger comforts prevalent at the time the body was constructed. Seats are of the reclining type and are set on large seat centers. Baggage facilities are ample to take care of all luggage. Motors and running gears are ample to sustain high road speeds without mechanical failure.

Arc welding as applied to the bus building industry especially in the construction of bodies is confined to relatively thin gauges, not heavier than ten gauge and not lighter than 24 gauge. Welding these extremely light gauges requires considerable skill on the part of the operator. It is our experience that a man accustomed to heavier welding will not produce as good a quality of work as a man who is, figuratively speaking, broken in on the light gauges first. Since body construction is essentially an integral unit, it is quite necessary that the welding be of the highest quality in order to eliminate failure in one of these joints.

In the introduction of high tensile steels, it was imperative to sufficiently acquaint the shop with the new fabricating methods which were necessary. Since these new alloy steels have considerably higher physical properties, it is obvious that they would be more difficult to form in a press brake and other shop machinery. In light gauges we have found that the high tensile steels can be treated practically the same as ordinary cold rolled mild steel. In the heavier gauges, how-

ever, it is advisable to allow a radius of at least twice the sheet thickness when flanging 90 degrees or more. Springback is very slightly more than that encountered in ordinary mild steel.

The high tensile steels can be very satisfactorily welded. The strength of the welds, if properly done, is practically equal to that of the parent metal and in some cases, slightly more. We have found that slightly less heat is required, as well as a somewhat slower speed. Several different welding electrodes have given good results.

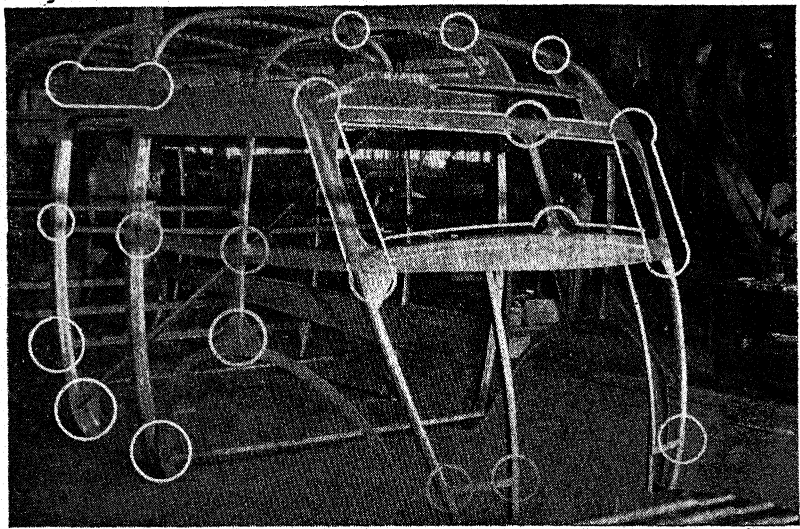

Fig. 2. Front-end frame work of bus. Circles indicate arc welded joints.

Since a good share of the welding done in our plant is on light gauges, it is quite necessary that care be taken in not burning, cratering or oxydizing the metal. For this reason we normally prefer a coated rod of mild steel quality. We do not favor the use of an alloy rod of chemical content similar to the parent metal because in a great number of cases the weld should be normalized or strain relieved. That operation is practically impossible in the framework of a bus. Also, the weld when made with a mild steel rod will tend to absorb alloying elements from the parent metal up to 50 per cent of the parent metal content. This percentage will decrease considerably if more than one pass is made on the weld. One added value of the use of a mild steel welding rod on high tensile steel is that the maximum amount of ductility is obtained, this being very important in the framework of a bus.

Warpage in flat sheets due to welding is a problem which is of great importance and one which cannot be lightly dwelt upon. Several means are used in welding large flat surfaces of light gauges to reduce this warpage to a minimum. First, the sheet to be welded can be tacked by one inch intermittent welds so as not to concentrate too much heat on the edge of the sheet. Second, a paste composed of asbestos soaked in water can be applied to the metal a short distance from the weld,

thus preventing the heat from traveling any great distance. This particular method has a decided quenching effect on the weld and in some cases might produce strains in the metal. However, in points of lesser structural importance, we find this method quite satisfactory. Third, placement of the weld slightly past the start of a curve on the flat sheet, thus confining the heat to the rounded section where it is dissipated evenly enough to eliminate buckling. Warpage on flat sheets has also been kept to a minimum by careful selection of the type of rod used.

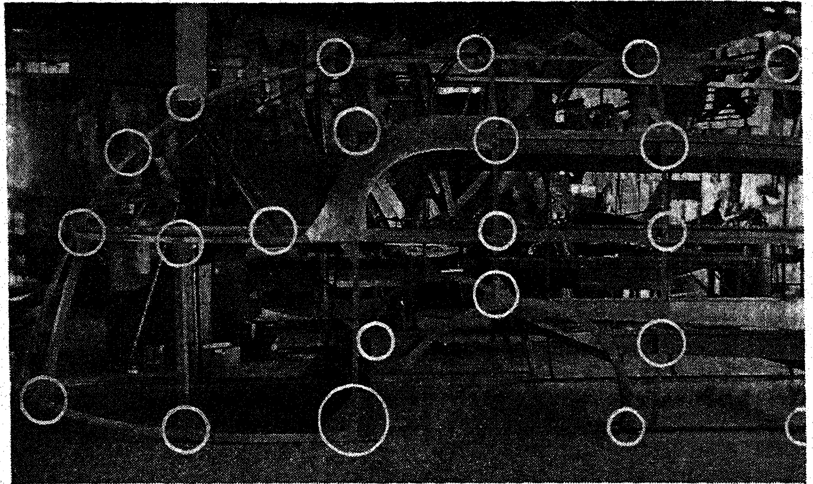

Fig. 3. Rear end bus body framing. Circles indicate arc welded joints.

Arc welding of bodies in our plant is a very broad term. Many different types of weld conditions are encountered and by noting the encircled joints in Figs. 2, 3, and 4 some idea of the amount of welding necessary on these bodies can be gathered. From this multiplicity of welds it can be seen that the entire strength of the unit depends on the quality of the welded joint.

With the advent of aluminum alloy panels, most of which are heat-treated, care is taken to make sure that no welding is done near this material. Because of the very nature of this material, heat which initially gives it strength, will also destroy its strength. The only exceptions to this rule are the front and rear quarter panels, which are fabricated from large sheets of hand-hammered un-heat treated aluminum alloy. Here again welding saves the cost of expensive dies, for these large sheets are composed of a number of smaller sheets welded together and finished off smooth.

Arc welding is important to the fabrication of bus bodies in dozens of different ways. It has made possible types of construction which are certainly the cheapest and most satisfactory methods. This is true especially from the standpoint of being able to vary the design and style at will, without having to rebuild all of the dies and jigs necessary in

mass production. Our production is strictly a custom-built type with very few models of the same types being produced.

Conclusion.—Arc welding has been, in the case of our production of our particular type of body, a means of cheaply and efficiently producing a job of very high quality and stamina. This has been proved by the millions of miles of service which our bodies have rendered. Certainly, over such a period of time inherently weak points would be brought to light and remedied.

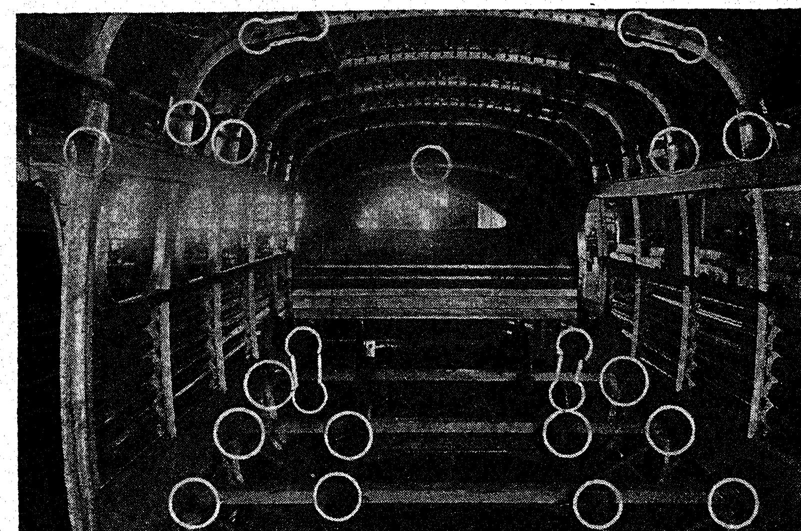

Fig. 4. Inside view of body with paneling attached. Circles indicate arc welded joints.

Of particular advantage is the fact that this type of welding is mobile enough that many changes in shape and style can be had with little cost increase to the customer. Essentially it is by far the cheapest method of fabricating these bodies. This saving which can be effected can thus be passed on to the customer and results in increased sales at reasonable profits. In this day of competition it is imperative to be able to produce an item as cheaply as possible and yet as substantial as possible in order to continue operation, and we feel that arc welding has done just that in our plant.

The arc welder has been particularly useful in the construction of these bodies because it is not limited to one type of metal. We are welding high tensile steel, stainless steel, mild steel, and aluminum alloy in our shop and are having very good luck with all of them.

Chapter VI—Trailerized Tanks*

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The subject of this paper is the design of a trailer unit, Fig. 1, used to haul liquids such as gasoline, fuel oil, milk, printer's ink, etc. This design has been treated as a trailer rather than a tank because the new design features to which arc welding is applied relate to that part of the unit which makes it an automotive trailer. There is no new design involved in the tank proper.

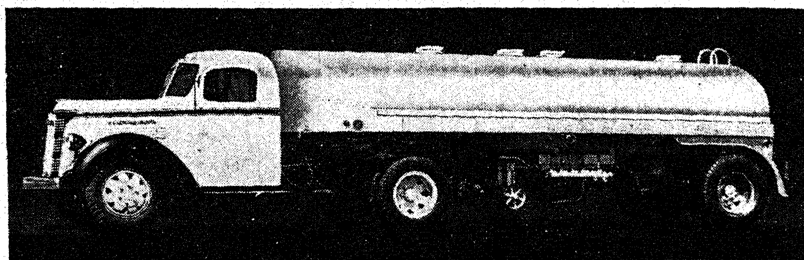

Fig. 1. Trailerized tank of arc welded design.

Since the truck transportation industry grew to the point where loads had to be restricted by legislation to preserve the highways and to keep them safe for the motoring public, the highway commissions of all states have limited the gross weight of a vehicle or a train of vehicles. The gross weight which may be carried on each axle is also restricted. This legislation puts a burden on the manufacturers of hauling equipment to furnish vehicles which contain as low a dead weight, or tare, as it is possible to build economically and which will stand up under the severe service imposed on truck equipment.

The semi-trailer operation is a particularly popular one. Among the principal reasons for this popularity are the low cost of the unit per pound of payload, the ease of manipulation, and the fact that through this style of equipment, the least dead weight for a given gross can be obtained.

The original designs of liquid bulk-hauling semi-trailer units consisted of a conventional tank mounted on a standard trailer frame in the same manner as they are mounted on trucks. The first attempts to lighten the weight of this equipment consisted of the application of high tensile strength steel to reduce the shell sheet thicknesses, or in the replacement of steel with aluminum.

A standard trailer will carry a tank and payload weight of 30,000

*Trade name—copyrighted.

pounds plus its own weight of 3650 pounds. The trailer running gear which includes springs, axle, wheels, rims, tires, brakes and radius rod is fastened to the trailer frame by spring hangers riveted to the frame. The necessary cross members of the frame are riveted to the side rails. The kingpin by which the trailer is towed is mounted on a floating plate which is called the upper fifth wheel. This plate oscillates on a shaft. The motion is lateral. This allows the tractor to twist with respect to the trailer without imposing a torque on the trailer frame which, due to its design, has an extremely low tortional rigidity.

This tank on the conventional trailer is mounted in a cradle and secured to this cradle by means of bands bolted thereto.

The cradle in turn is bolted to the trailer frame. This combination unit weighs 7640 pounds or 1.91 pounds per gallon.

The insistent demand of trucking operators to obtain greater payloads in order to reduce the cost of hauling resulted in the development of the design of the unit shown in Fig. 2. This unit consists of a tank with supports for the running gear and fifth wheel welded directly to the tank shell, thus eliminating the trailer frame entirely and simplifying the cradle or support member. In analyzing the elimination of the trailer frame, we determined the function which the frame performed in the combination unit. The frame supported the five cradle members which had the weight of the tank and payload imposed upon them. The trailer frame transferred these five statically indeterminate loads to the spring hangers and fifth wheel bearings, which in turn supported the entire unit. In transferring these loads the trailer frame acted as a beam. The trailer frame has a section modulus of $17.6''^3$. The tank shell has a section modulus of $1.255x[(A+t)^4—A^4]/(A+t)$. This equals $300''^3$ in full section and $162''^3$ in reduced or cut away section when the shell is made of 14 gauge and when it is so reinforced that it will retain its cross section without appreciable distortion.

From these figures and the stress analysis on the comparative section moduli of the trailer frame and tank we see that the tank has a beam strength nine times larger than the trailer frame, so that we can substitute the tank structure for the trailer frame insofar as its beam strength is concerned.

The stresses of towing must be carried by the tank if we eliminate the trailer frame. On a tractor with an 18,000 pound load the maximum towing force obtainable would be approximately 9500 pounds. If we divide the cross sectional area of the shell into the towing force, the stress induced will amount to 530 pounds per sq. in. The other load which the trailer frame must resist is that of the braking. The forces produced by brake application are a function of the weight on the axle and are approximately equal to the maximum towing force or 9500 pounds. The direct braking force induces a direct tension stress in the shell of 530 pounds but also increases the bending due to the torque produced by the eccentric application of this brake load.

Bending, shear, shear stress, compressive stress and tensile stress during the application of the trailer brakes only induce the highest stresses in the unit. The maximum direct tensile stress is 3100 pounds per sq. in. Multiplying this "steady state" stress by a dynamic load factor of 2 produces a maximum stress of 6200 per sq. in. tension. This stress

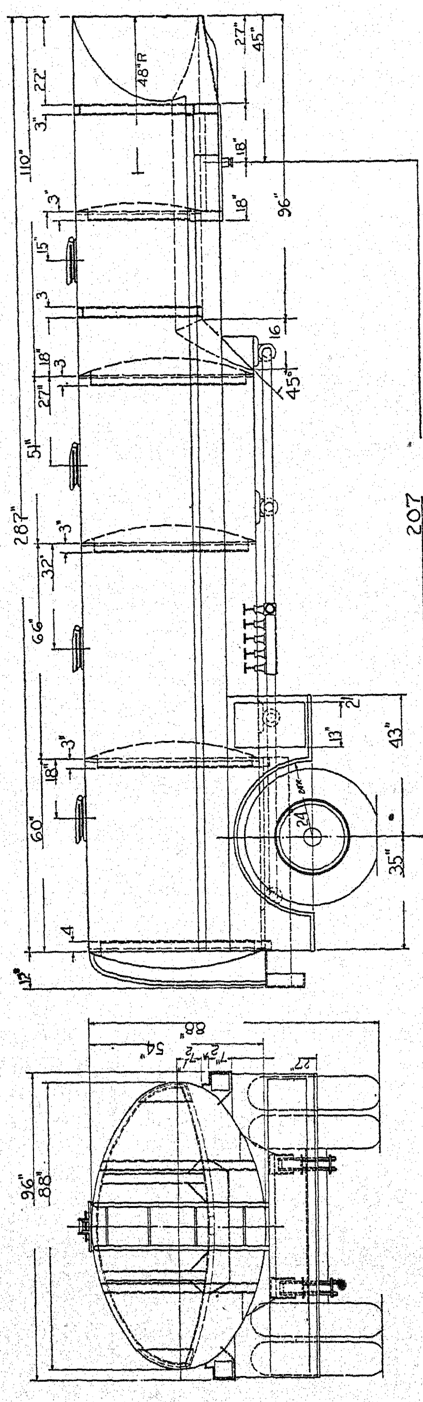

Fig. 2. Design of trailerized tank.

produces a safety factor of 9.7 when using an ultimate strength of the welds in high tensile strength steel sheets of 60,000 pounds per sq. in. The 14 gauge high tensile strength sheets have been welded with mild steel electrodes because it has been our desire to obtain ductility in the welds equal to, or greater than, the sheet. From tests conducted in the laboratory it has been found that for this application it is unnecessary to weld 14 gauge high tensile strength sheets with an electrode which produces an alloy weld metal of either the same analysis as the sheet or some different analysis. Stress relieving a tank of this type will not improve the structure to any appreciable extent. Therefore, the cost of stress relieving is considered an unnecessary expenditure. The welds in the vessel are to be used in the as-welded condition and the tensile strength closely approaches that of the alloy sheet. The ultimate tensile strength of 60,000 pounds per sq. in. used in calculating the safety factor in this analysis is conservative.

Intermittent welds have been used very sparingly. In the understructure which supports the springs and the joint between the cradle support members and the tank shell, all welds are continuous. The welds are relatively light and are not stressed to the highest allowable tensile stress that could be used considering their tensile strength. The continuous welding on this portion of the structure is used due to the more uniform stress distribution obtained. It is highly essential in automotive equipment that "stress-raisers" such as sharp corners, rapid changes in section, etc. be eliminated. Intermittent welds on equipment of this type will have some concentration of stress at the ends of each weld. The lack of uniformity in the contour of the stop of an intermittent weld plus the possibility of a slight shrink crack in the crater left by the arc would be an ideal point for a fatigue failure to start. By the use of a proper welding procedure, warpage in these light gauge high tensile steel sheets has been reduced to a minimum despite the fact that the welds are continuous rather than intermittent.

With induced stresses in normal operation as low as they were here it appears unnecessary for the designer to use a high tensile strength steel sheet. However, in the light gauge used in this design the ease with which the shell could be ruptured in an accident must be considered. The American Petroleum Institute and the National Fire Protection Association have designated minimum thicknesses for various tensile strengths of steel. By applying high tensile strength steel the gauge can be reduced and the code complied with. The other advantage of the high tensile strength steel is the increased endurance limit of the material. Automotive equipment is subjected to repeated and reversed stresses through the vibrations induced during operation. Rapid acceleration and deceleration in both the vertical and horizontal planes produces surge loads on the shell and heads of the vessel which also induce vibrations. Vibrations in the shell of a tank of this type are damped out at the reinforcing rings and at the heads. This means that the damping stresses are transferred through a weld and the use of steel with a high endurance limit increases the stress which can safely be induced in the area adjacent to the weld which has been affected by the heat of welding without producing a fatigue failure. The trailer frame also distributed the concentrated loads at the spring hangers without affecting the tank.

The spring support design shown in Fig. 3 is a completely arc welded running gear support. The principal object of this design is the elimination of concentrated stresses in the shell and heads to which the springs are fastened. The box section cradle member produces resistance to bending in both the horizontal and the vertical planes. This section also transfers the compression from the spring hanger proper to the head stiffener. It is a very efficient member for resisting the horizontal bending, the

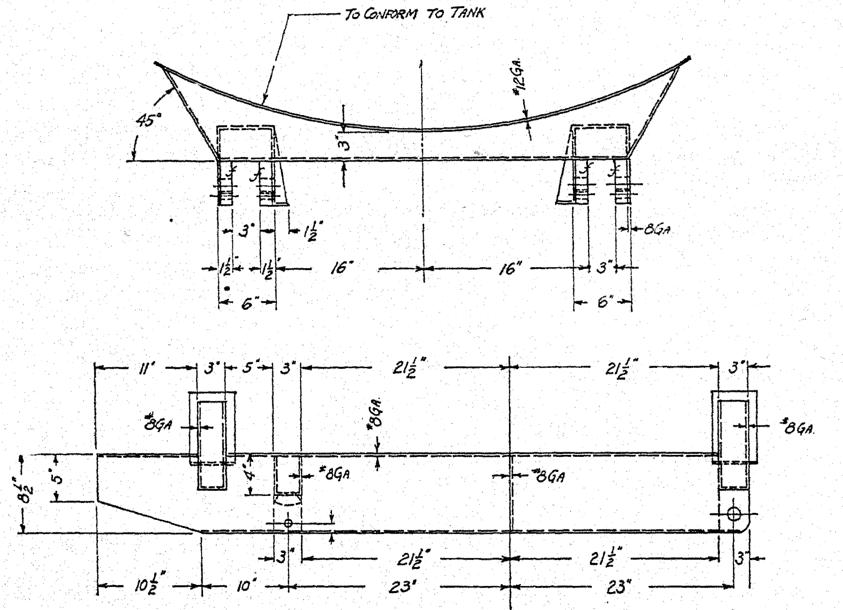

Fig. 3. Spring support is completely arc welded.

vertical bending and the direct compression. The U-shaped longitudinal member which connects the two transverse cradle members, is made of 10 gauge steel and acts as a strut to eliminate local bending of the front cradle member during the application of brakes. This longitudinal member forces the front transverse cradle and the transverse cradle to act as a rigid unit, thus transferring the brake load to bending of the entire tank shell. The bending induced by this brake load is then treated as a beam with eccentric axial loads.

The cross members to which the spring hangers and frame members are attached are welded to a pad which is in turn welded to the shell of the tank. This transition plate has been added to give a more gradual change in section than would be produced by welding the cross member directly to the shell. Also, in the case of an accident involving the running gear, there will be less tendency to rupture the tank shell if this plate is used.

The shackle pin by which the spring is attached to the tank unit is secured in a hole bored in the longitudinal frame member. This hole is reinforced on each side of the longitudinal member by a piece of $1\frac{1}{2}''\times3''\times5''$ plate which is welded to the longitudinal member. This plate not

only acts as a bearing for the shackle pin but as a spacer for the spring. The boring and reaming of the hole which receives the shackle pin and the milling of the two faces of the $1\frac{1}{2}''$ thick plate which act as the spring hanger are done when the longitudinal member is welded up complete, ready to be welded to the tank structure. This is the only machining that is required on the entire running gear of this unit.

The running gear assembly design eliminates the use of a radius rod which absorbs the direct brake force and a portion of the brake torque in the running gear on the standard trailer. This design eliminating the radius rod makes use of the spring as a radius rod. Eliminating the radius rod saves the weight of the rod and the bearings to which the rod ends are attached, and also eliminates four points of wear on the unit. Although the original design had a compound spring the same as the trailer, the design of the axle suspension was further simplified by using a simple spring. This change can be made due to the fact that a tank used to haul liquids has a definite predetermined load whereas a standard trailer, which may have a platform or a van body mounted on it, will be subjected to greatly varying loads and can be very easily overloaded. In order to protect this type of equipment during such overloads, the trailer companies resort to compound springs. This double spring also provides easier riding when a unit is lightly loaded. Since the riding qualities of a liquid tank are not an important problem, a compound spring is not required.

The upper fifth wheel, (See Fig. 4), used in this design consists of a plate to which the heat treated forged kingpin is riveted. It is fastened to the tank by welding direct to two cross members similar to those used to support the running gear. The oscillating motion which is obtained in a

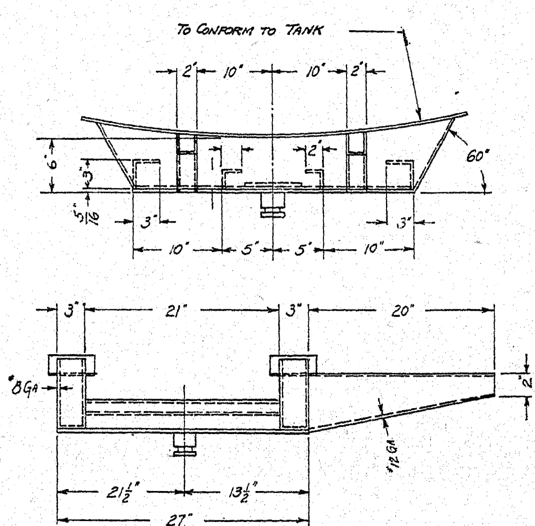

Fig. 4. Upper fifth wheel of trailerized tank.

combination trailer and tank unit is attained on this unit by means of a lower fifth wheel plate which oscillates both laterally and transversely, acting as a universal joint. Using this type of fifth wheel arrangement reduces the eccentricity of the towing load, it reduces the possibility for a localized twist of the cross member supporting the plate and simplifies the entire welded structure at this point. If this type of fifth wheel arrangement is not used, the additional clearance required for the floating type of upper fifth wheel would not allow the designer to take full advantage of lowering the unit by making use of the clearances available at the other points which affect the height of the tank.

The spring suspension shown in Fig. 3 without the helper spring lowers the tank unit 2½″ without the necessity of a spring which is slung below the axle. Through the elimination of the helper spring and the radius rod 2½″ of clearance between the spring shackle bolt and the bottom of the tank is made available. This can be used to lower the tank. The elimination of the trailer frame allowed the unit to be lowered in addition to this 2½″ due to the fact that there is no interference of the trailer frame with the pipe lines from the various compartments into which the tank is divided. The larger the number of compartments, the more difficult it is to pipe a unit mounted on a trailer unless the unit is raised a sufficient amount to allow the pipe lines to be placed between the top of the trailer frame and the bottom of the tank. The ease with which this new designed type of unit can be piped reduces the cost of piping to some extent. Lowering the center of gravity of the tank and unit is extremely desirable because it produces greater stability of the unit by reducing the tendency to side sway. There is less tendency for the unit to roll over on sharp curves or when the unit skids on icy pavement. This increased stability is one of the best selling points for this new design of equipment.

The catwalk was made of diamond checkered tread plate placed on top of the tank shell either adjacent to the manholes or spanning the manholes. To further reduce the weight of the unit, a 24″ wide strip of 14 gauge treadplate replaced a portion of the tank shell. Thus, the sheet serves two purposes—both as catwalk and tank shell. This weight saving, however, required an additional longitudinal butt joint so that the cost is slightly higher than that of the catwalk which was fastened to the shell by bolting to welded brackets.

On the side of these trailer tanks there is a strip of steel which is used as a side bumper and also for carrying hose to be used when the tank is being emptied. In the original design of the tanks which were mounted on trailers, two angles with holes tapped in them were skip-welded to the tank shell and the sheet metal hose tube compartment was fastened to the angles by stove bolts or self-tapping sheet metal screws. The only apparent reason for screwing the hose tube on was to provide a means for disassembling. There does not appear to be any reason for this feature so in the new design the hose tube was welded directly to the tank shell, thus saving the weight of the longitudinal angles, the expensive drilled and tapped holes and the bolting operation.

The following table is a weight breakdown of the two units:

WEIGHT COMPARISON TRAILERIZED TANK AND COMBINATION TANK AND TRAILER

Part Compared	Trailerized Tank	Combination Tank and Trailer
Shell	2194	2033
Heads	682	562
Rings	205	171
Manholes	140	140
Outlets	28	28
Stiffeners on Heads	216	160
Cradle Members	136	210
Catwalk	38	86
Hose Tubes	124	270
Ladder	24	24
Lights	18	18
Upper Fifth Wheel	140	
Spring Supports	146	
Springs		
U-Bolts & Shackle Pins	22	
Springs Seats	20	
Tie Bands		125
Pipe Lines	78	78
Emergency Valves	86	86
Mounting Bars & Bolts	68	68
Skirting	105	123
Control Box	28	28
Brake Operating Parts	70	
Tires	608	
Axle & Brakes	670	
Wheels & Rims	384	
Springs	320	
Trailer		3450
Complete Unit	6550	7640

NOTE:

The combination trailer and tank unit with which the trailerized tank described in this paper is compared is not an obsolete piece of equipment. It is the most modern product which the manufacturers of these combination units are producing today and until this newly developed tank unit was manufactured by this company, our combination unit was of a design similar to that shown in Fig. 2. The combination tank and trailer unit as well as the trailerized tank are the products of an industry which has used arc welding as the chief fabricating process since its inception in the industrial field. Because the combination unit was stripped of as much excess weight as possible, a radical design change such as this trailerized tank was necessary in order to produce an appreciable weight saving.

From the above comparison it can be seen that the new design results in an increase in the payload of 1100 pounds which is equivalent to 175 gallons of gasoline. This 175 gallons of payload is a bonus load. The old style equipment has exactly the same gross weight, therefore the cost of transporting the old style combination unit over a given route was the

same as the cost of transporting the trailerized unit over the same route. The additional revenue provided for by the increased payload will greatly increase the percentage of profit because the entire earnings of this bonus load are profit.

Since the first of these units was placed in operation approximately sixty of them have been constructed and placed in operation. They have been well received by the trade and have performed with complete satisfaction.

Due to the fact that the standard trailer was manufactured by the trailer companies, no cost data is available which can be compared with

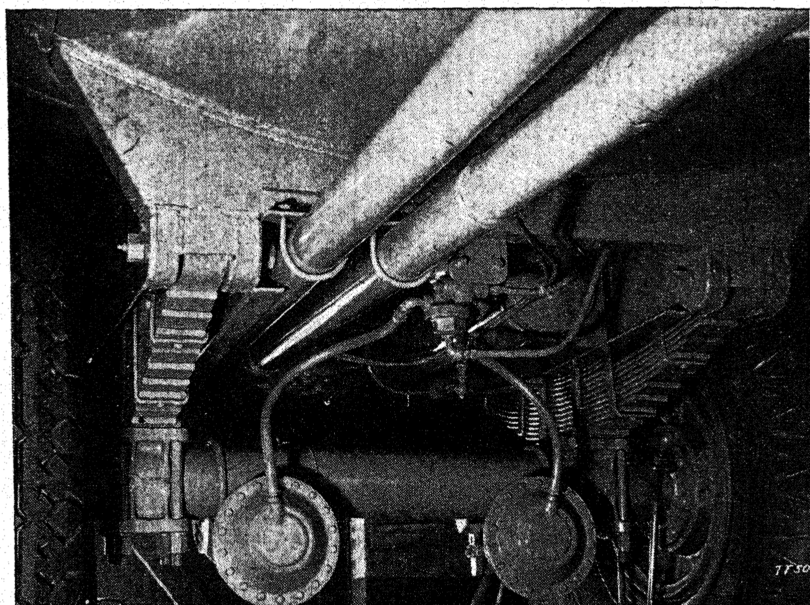

Fig. 5. Understructure of trailerized tank.

the new design. The construction of the complete trailer unit is a new product.

Inspection of Figs. 5 and 6, which are photographs of the understructure of the tank, will reveal that the new unit has very few parts, requires little machining and will unquestionably be cheaper to fabricate than the combination unit. The combination unit not only contained a more expensive trailer unit but also required expensive cradle members and hold-down bands which had to be bolted together. The tank unit which was mounted on the conventional trailer had only forty feet less welding than the completely welded unit described in this paper despite the thirty 5/8″ bolts required to hold the tank to the trailer.

Through the simplified design of the running gear of this new unit the cost of maintenance is reduced due to the elimination of a large percentage of the moving parts on the running gear. The elimination of spring

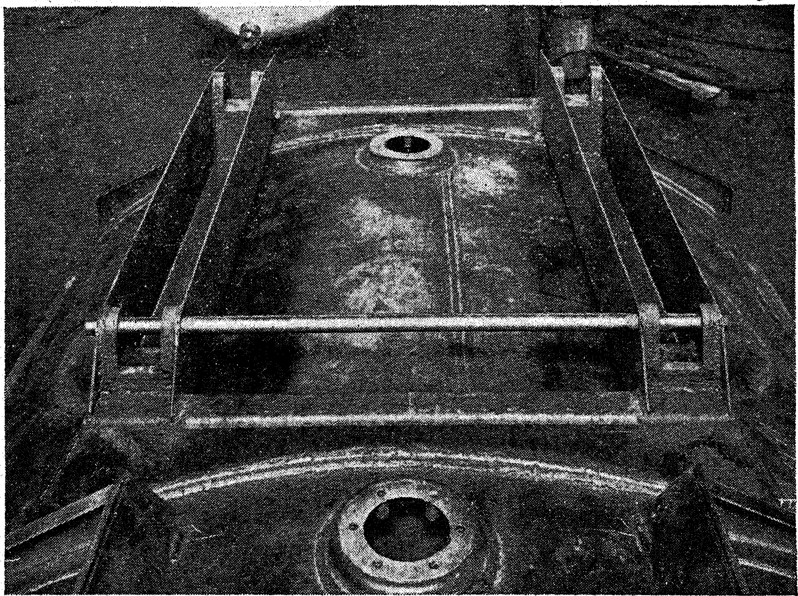

Fig. 6. Welding details of trailerized tank.

shackles and radius rods eliminates ten points which previously required regular greasing. Lowering the unit provides greater safety to both the operator and the general motoring public. It also greatly improves the appearance of these units.

The above named advantages are, of course, secondary to the increase in payload provided for in this design.

Chapter VII—Design and Production of an All-Welded Track Roller Frame Assembly

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It is probable that elsewhere, as well as in our organization, welding as a commercial process first entered the industry through the maintenance divisions. Since the earliest dates of its use, the process has had a definite economic advantage in its application to the type of industrial repairs and maintenance work which have had to be done hurriedly. In these applications, its use was the expedient which shortened expensive delays due to unavoidable shut-downs for repairs. Repair welds could be overdesigned beyond our present-day imaginations in an effort to satisfy the then somewhat justified scoffers who were skeptical of the process, and still maintain an economic advantage over optional methods of repair The requirements of adequate control under these circumstances were not severe.

Perhaps it was the attractive economy of the process in such applications that led to its gradual filtering into use in production.

During the period when welding began to be used in manufacturing, it was essentially a substitute process. Methods of controlling the materials and the application of the process were in their formative stages and had to be developed. Designers had yet to learn the best use of welding and were still somewhat reluctant to work freely with the usual design factors. Resultant designs were strongly suggestive of riveted and cast construction and, at their best, were simply less expensive assemblies than had been produced previously as riveted or cast units. The advantages of the process, as the world now knows them, were not fully realized.

The reluctance on the part of industry as a whole to take up the process has been a good thing for welding, however, because it made imperative the development of suitable methods of qualifying welders, of controlling materials, and of inspecting finished welds. Research in the field by the producers and users of welding materials and equipment has built up a valuable experience on which we successfully apply welding today, and has put it in the field as a distinct process, thoroughly versatile when properly applied, and characterized by a variety of important advantages.

In the Caterpillar Tractor Co. we have experienced a development in the application of welding which parallels the general development. The first welded designs produced were substitute designs—cautious attempts to pass on to our customers the economic advantages of welding, without lowering the high standards of quality in performance we endeavor to build into all of our products. Methods of control were promptly set up, have undergone continuous development through the succeeding years, and are still progressing. We have been producing welded parts for many years, based upon the use of controlled

materials and welding applied by qualified welders, which are distinct designs, representative of the application of welding to production that carries no suggestion of riveted or cast construction. Such experience in the use of this relatively new and extremely useful tool, coupled with our closely maintained contact with machines in service all over the world, has given us faith in the proper use of the process.

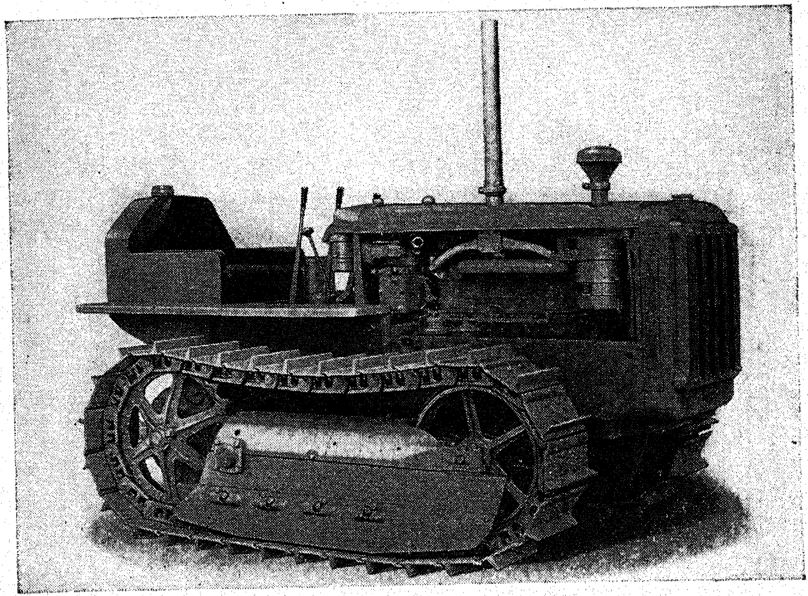

Fig. 1. Caterpillar tractor whose roller frame is the subject of this paper.

If there is any conclusion to be drawn from this experience it is that welding as a manufacturing process or tool should be considered on its merits in every application at all feasible, in each of the several aspects of design for function and appearance, production, performance and service, sale, and cost. When it is possible to carefully weigh the merits of assembly by welding in each of these important divisions against those of other possible processes, welding will frequently be found the best process to use. Although we have in our products hundreds of welded parts, varying in weight from a few ounces to several thousand pounds, each of these applications of welding has had to run the gauntlet of a many-sided consideration before it was released for production with the positive indication that welding was the best method we could use in its manufacture. It is true there are parts for which, for some consideration under one or more of the above headings, another process is superior. To use welding for such an application would not be profitable to anyone for very long.

In our business, where the product is serviced as long as it exists, it is mandatory that every aspect of the circular traverse of the product from drafting board through production, sale, and use, to engineering observation of the field performance throughout the life of the product,

be weighed in the creation of new designs. In this, an adequately controlled process of welding in assembly has come through the years to be a very useful tool, and one which possesses merits worth considering all along this circular path.

In this paper, an attempt will be made to tell the story of only one of the assemblies we make by welding. Although this is a new part, and different in some respects from its predecessors, our previous experience with this particular part pointed so definitely to a welded design, that one will with difficulty find it has any vestige of resemblance to a cast or riveted counterpart. It was designed "from scratch" as a welded part.

By describing the design of the part, our methods of control, production of the part, its inspection, its assembly to the tractor, as well as its performance in use, an attempt will be made to show why we have found in the properly controlled use of welding, a distinct and meritorious production tool.

A track roller frame assembly is what we call the frame on which the weight of the tractor rests and rolls. Two of these are required per tractor. Fig. 2 is a working drawing of the subject of this paper, the frame of a recently introduced model diesel tractor.

The requirements of this assembly are more numerous and important than would appear to the casual observer, and it is a fact that a large volume might be written concerning the successful attempts to discover and satisfy these requirements during the many years since the original "Caterpillar" type of propulsion first made its appearance.

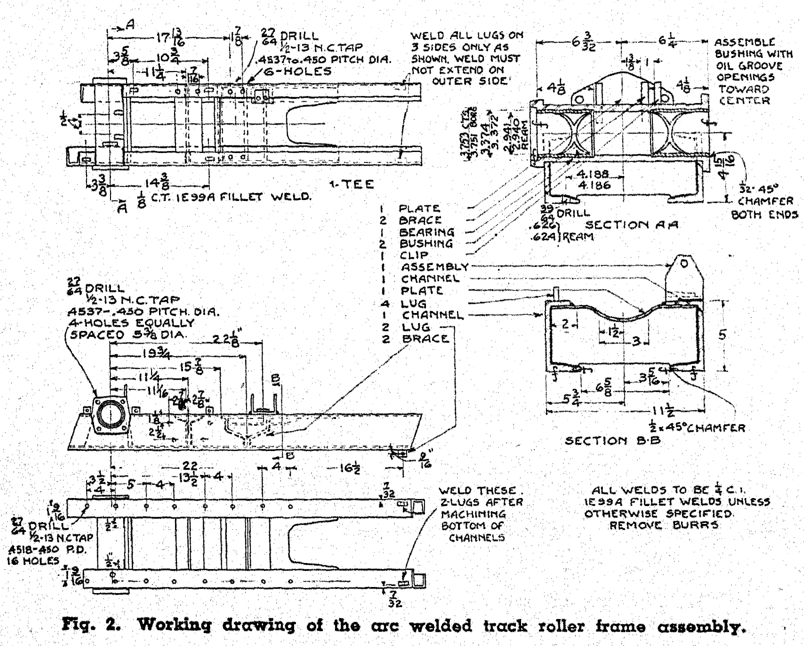

Fig. 2. Working drawing of the arc welded track roller frame assembly.

Briefly and in general, the requirements classify themselves as those of function, appearance, production, and cost.

In order properly to function, this frame must: (1) Transfer the weight of the tractor to the rollers; (2) support the rollers, and maintain their alignment; (3) support the front idler and maintain its alignment; (4) provide for the oscillation of the track; (5) absorb shock; (6) have provision for maintaining tension in track; (7) allow adjustment of track tension; (8) resist side thrust in turning, and in working on side slopes; (9) permit ready accessibility and replacement if this becomes necessary; (10) provide support for the attachment of miscellaneous special equipment such as bull dozers, side boom lifts, snow plows, etc. Those are the main demands of function.

As in other products, the requirements of appearance in design are not complex as long as they are kept in mind. The lines of the part should conform to those of the complete tractor; there should be no obtrusive projections; the part should show evidence of good workmanship throughout; and it should appear to conform with the rest of the tractor in strength. These are simple requirements, asking only a modicum of alertness on the part of the designer.

Actual production of the part imposes few restrictions on a designer in our organization when the part is to be produced in large quantities, for the plant is adequately equipped, is arranged to be easily adapted to many types of work. It is essential, however, that the number of different parts entering the assembly be a minimum, that the part used in ultimate assembly of the tractor on the line is one which can be handled safely and easily with the proper tools, and that the availability to the production departments of materials used in the design be certain and stable.

The cost requirement is one that good designers keep in mind all of the time, but it is also true at Caterpillar Tractor Co. that a really superior design will always be placed into use, even though its manufacturing cost be greater. The reason for this is a firm conviction that when superior designs are used there is a reduction in ultimate cost in the performance of the work for which the product was intended. So the cost consideration, within the limits of common sense, is a relatively unimportant factor in our design.

Given that brief resumé of the principal requirements of the design, the reader will agree there are several methods of construction which might be used. He may well ask, "Why was this particular method chosen?"

If we enumerate and examine the methods which might be used, with regard to the requirements above, and assuming for the minute that the design shown in Fig. 2 meets all the requirements, we can answer that question. Let us consider making the assembly; 1) of standard shapes, plates, castings, and forgings riveted and, or, bolted together; 2) same as above with a combination with welding; 3) integral as a steel casting; or 4) entirely welded using standard sections where possible, special sections where necessary.

Referring briefly to the riveted or bolted construction, we see that any reduction in the size of replacement unit which this might offer as an advantage would be offset by the possibility of losing positive

alignment of the rollers and idler—as well as the loss of rigidity where it is required. This objection would become a very serious one for tractors expected to perform on irregular rocky footing, and would give rise to serious wear of the track and rotating parts. This type of construction was suitable years ago and served very well for a time. In fact, it may be due to some of the older designs "taking it" for short periods in the then "impossible" applications that led to the continuous use of tractors on such work, and brought on the requirement of improved alignment and rigidity which we have had with us so many years. When it is considered that many tractors are working over the 20,000-hour mark, at hard pulling over any terrain, and this contrasted to something familiar such as the average automobile life, for example, the design requirements of this type of equipment become particularly striking. Riveted and bolted connections, our experience has indicated, must be held to the minimum consistent with the most efficient servicing. In this type of application, therefore, their use has been superseded many years ago.

The use of a steel casting here is conceivable, but reference to the details will show that much heavier sections would be required by the best foundry practice. Usual tolerances, as cast, would be such that a larger number of machining operations would be required than on the present design, and the usual annealing process would also be required. Further, no operation performed on the welded assembly, other than the actual welding would be saved through the use of a casting.

Thus, briefly, we see ourselves guided to the present design—the "why?" briefly answered.

The welded assembly of rolled steel parts satisfies all of the requirements simply and effectively. It will be noticed by reference to the assembly drawing, Fig. 2, that in order to provide the desired alignment to the roller assemblies which are subsequently attached to this frame, a machining operation is necessary on the lower flange of the side channels. Also, it was desired to fasten these rollers by means of capscrews into tapped holes in the frame. These two items made a thick flange desirable, but since standard channels are symmetrical and there was no point in having the upper flange heavier than the standard structural flange, a special section was resorted to. This section is clearly shown in Section "BB" of Fig. 2. The use of this section, with the bottom flange broached after assembly, enables the top flange to be used as a guide and support for the adjustable front idler, shown at "B", Fig. 3, without any further machining. The position of the idler can be changed by means of a bolt concentric with the helical recoil spring just visible at "A", Fig. 3. Since the spring maintains the required tension in the track and absorbs shocks from objects met in travel, the front idler necessarily has freedom in a direction parallel to the axis of the spring. This movement is guided by the top flanges of the channels. (See "D", Fig. 3.) The channels are amply rigid for the short unsupported length near the front, to resist the twisting action to which the track subjects the frame in passing over the front idler on irregular ground. Part of the weight of the tractor is transferred from the equalizer spring to the track

roller frame through the hardened steel block (shown at "A", Fig. 4.) The spring simply rests on this block, can only transfer vertical loads. The balance of the weight of the tractor is transferred to the frame through the bearing at the rear of the frame. (See "B", Fig. 4, and "A", Fig. 5.) An interesting part, this bearing is made from standard

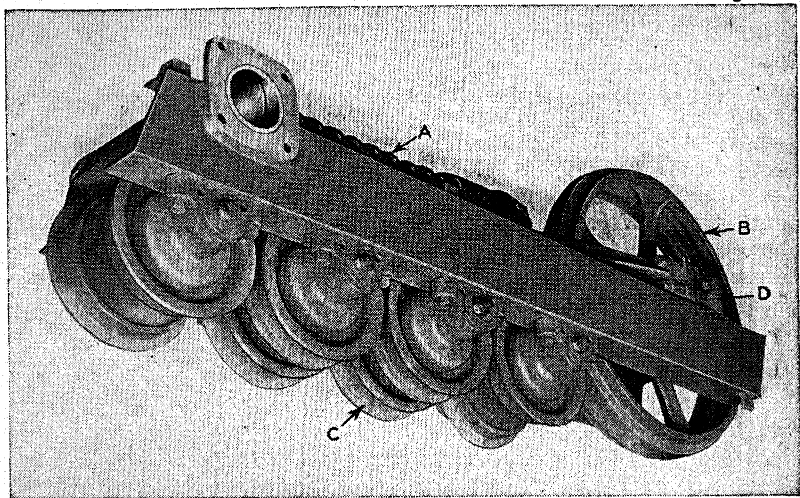

Fig. 3. Track roller frame with helical recoil spring, "A", and adjustable front idler, "B".

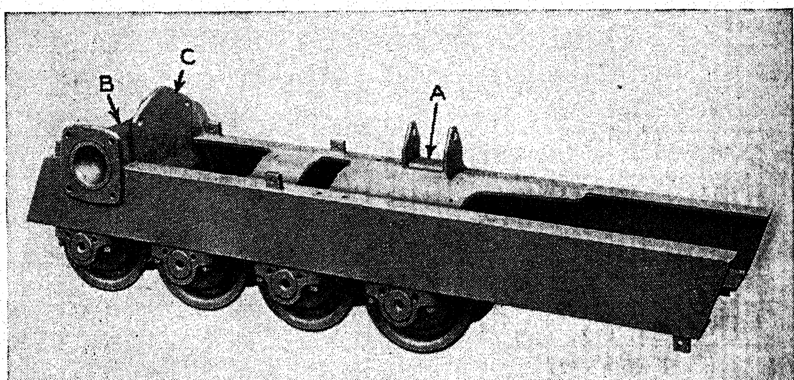

Fig. 4. Track roller frame without idler, showing block "A" through which part of tractor weight is transferred to the frame; and bearing "B" through which balance of weight is transferred to frame.

tubing upset at each end to form the flanges shown. After assembly it is bored, bushed at each end (see "B", Fig. 5), and line-reamed to receive the pivot shaft. Oscillation occurs about this shaft as a center. The plate, shown at "C", Fig. 4, is supported against the bearing by the braces "C", Fig. 6, and takes the reaction of the recoil spring. The members at "J" and "S", Fig. 6, are formed from plate

to add rigidity to the structure, and are curved to clear the recoil spring, as shown. The tee, at "B" in Fig. 6, is a standard structural section formed to the shape shown and cut to fit up well with the insides of the channels. Its purpose is to add rigidity to the frame. Six lugs, shown in the perspective sketch are tapped before assembly, and form fastenings for the guards, while the clip shown at "E", of Fig. 6, is simply a protection for a lubrication fitting in the top of the bearing.

Consideration of these details emphasizes the effectiveness of the method of construction chosen, and clearly indicates the difficulty which would attend an attempt to satisfy the requirements of the design by any other means.

A comparison of the cost to manufacture using this construction, however, with that using an integral cast frame of steel (the only option if welding were unknown or unreliable) is given in Table I.

TABLE I—COST COMPARISON

WELDED ASSEMBLY (Based on Finished Casting Cost of 100%)						STEEL CASTING (Based on Finished Cost of 100%)				
PARTS (See Figure 6)	MATERIAL	LABOR AND BURDEN	UNIT COST	NUMBER REQUIRED	TOTAL	MATERIAL	LABOR AND BURDEN	UNIT COST	NUMBER REQUIRED	TOTAL
1. Clip—E.....	.057	......	.057	1	.114					
2. Lug	.057	......	.057	2	.114					
3. Bushing	2.326	......	2.326	....	4.652	2.326		2.326		4.652
4. Plate—A	.846	.239	1.085	1	1.085					
5. Brace—S, T.	.434	.363	.797	2	1.594					
6. Lug	.040	......	.040	4	.160					
7. Plate—J	1.320	.508	1.829	1	1.829					
8. Brace—C	.034	.049	.083	2	.166					
9. Channel—R	3.302	1.108	4.320	1	4.320					
10. Channel—H	3.302	1.496	4.798	1	4.798					
11. Bearing—D	5.049	1.936	6.985	1	6.985					
12. Tee—B	.840	1.701	2.541	1	2.541					
13. Assembly—G	.340	.969	1.309	1	1.309					
14. Frame	.724	21.286	22.010	1	22.010	68.490	26.858	95.348	1	95.348
TOTAL					51.677					100.00

The actual production of the tractor roller frame has many interesting aspects, not only because it is completely welded, but also

because the rate of production must be consistently high enough to supply the power conveyor tractor assembly line. The production of both right and left hand frames alternately by the same operators on the same machines, although not unusual, is a further feature of interest from the manufacturing standpoint.

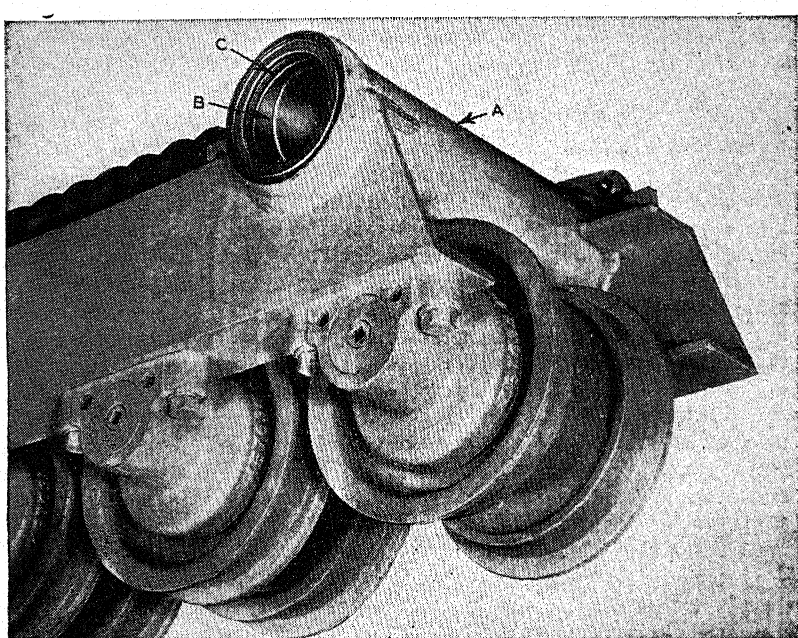

Fig. 5. Section of track roller frame showing bearing made from standard tubing upset.

The entire activity described here, with the execption of the operations performed on the material before it arrives at the tacking booth, takes place in a straight line about two hundred feet long. All of the required machines, including the surface broach, and a total of four separate welding booths are included in this space leaving plenty of room around each unit, and in each welding booth. The fact that conveyors are located at the proper height to permit rolling the work into fixtures without lifting, and that special tool equipment has been provided wherever necessary has contributed much to the satisfactory operation of the entire unit. Of interest from the welding point of view is the use of fixtures throughout to facilitate the work. It will be noted that these fixtures are themselves made principally by welding. Each welder has his own individual booth, enclosed on four sides by sheet metal extending from about eight inches off the floor to a height of about seven feet six inches, for the protection of neighboring machine operators or welders. A fan in each booth contributes much to the welder's comfort that might otherwise be lost by the use of enclosed booths.

These points and other interesting features of this activity can

be brought out nicely by a verbal journey in and out of the welding booths where the assembly is put together.

Outside of the tacker's booth we should find a store of the special channels which have been punched and shorn to the shape shown in Fig. 6. The bearing "D", Fig. 6, we would notice had been relieved of the fillet under the upset ends by turning. We would notice that the plate at "J" had been milled at the edges, and that the tee section had also been machined to 45 degrees along the edge of the top face would be apparent. A glance would show that all of the other parts entering the booth were punched and formed cold from plate.

Inside of the tacker's booth one fixture enables the man quickly to set both channels, the tee, braces "S" and "T" (previously tacked together), plate "A", and later plate "J" in the assembled position. The parts are all rigidly clamped in the correct position determined by gauging surfaces on the fixture which is arranged to accommodate either right or left hand frames. After those parts have been tacked, the frame is carried on a convenient hoist to another position in the same booth where the bearing and two braces "C" (Fig. 6) are tacked in place. The tacker, with the aid of the two fixtures, can easily supply frames to the two welders, occupying separate booths adjacent to his.

Inside either one of the next two booths a universal fixture assists the welder in his attempts to perform uniformly good work continuously. The frame can be rotated through 360 degrees about its longitudinal axis, and the channels can be placed vertical with either end down as well as in any intermediate position. Conveniently located stops on the fixture permit its ready adjustment to predetermined positions best suited to the weld being made.

From the two principal welding booths, the frames are placed on a conveyor, the slag and spatter cleaned off on the way to the press. The purpose of the press operation is to restore alignment and parallelism all around the frame when this has been decreased by welding. Our experience has indicated that when this can safely be done, it is more advantageous and gives a more uniform final alignment in all parts than attempts to control the slight distortion, which occurs in some degree anyway, by closer regulation of the order and distribution of the welding.

Following the straightening operation, the channels are surface broached on the bottom and along the inside of the bottom flanges as indicated by the f marks in Section "BB" of Fig. 2. The locating hole, shown in Section "AA" of the same drawing, serves to locate the frame for all subsequent machining. It is drilled and reamed following the broaching operation on the channels, and the frame moves to a special machine which bores and counterbores, faces, and chamfers the bearing. At their completion, the frame is indexed further to the right into the machine and the bronze bushings are dropped from the two feeding mechanisms and pressed into the bearing. Indexed again, the frame locates in the correct position for line reaming the bushings. This is accomplished by a motor-driven unit. As each frame enters the machine, another is discharged onto a conveyor for the subsequent operation.

Drilling and tapping of the several required holes is accomplished

on two machines. Here again the use of special tool equipment facilitates the work. In addition to the roll-over devices and conveyors which make locating the work easier, the multiple spindle drill is automatic and requires no attention from the operator after the frame has been clamped in place. The radial drill serves very well to tap the several holes required.

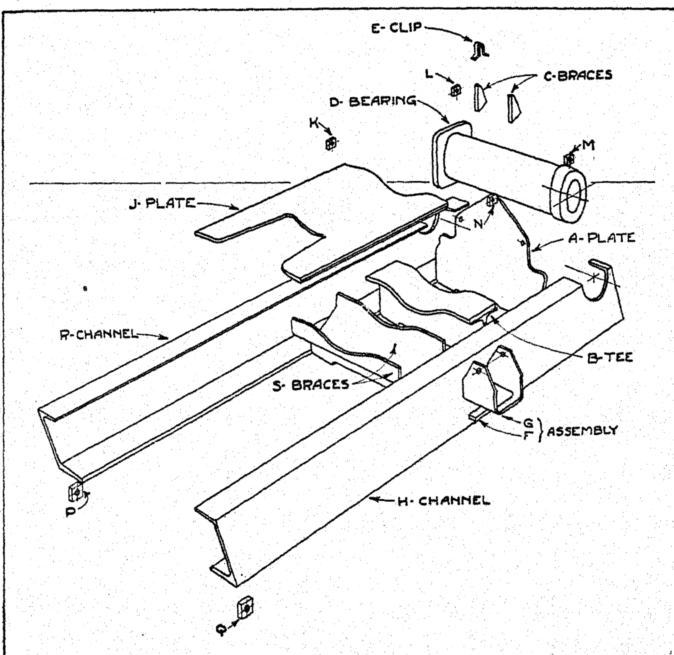

Fig. 6. Perspective sketch showing track roller frame.

Leaving the tapping station, the frame rolls along a conveyor to the welding booth. The six threaded lugs, as well as the clip "E" and the assembly "G-F", all shown in Fig 6, are welded in place at this station. The frame registers accurately to locating surfaces, and hinged elements on the fixture locate all of the parts remaining to be welded onto either right or left hand assemblies. Itself a welded product, this welding fixture can be rotated with little effort through 360 degrees about its longitudinal axis. Convenient stops at 180 degrees permit positioning the frame for the attachment of lugs on the lower flange of the channels (shown at "P" and "Q" of Fig. 6). Discharged from the booth on conveyor, the frame is cleaned up and prepared for inspection—a finished track roller frame assembly.

The importance of the accuracy with which the all-welded frame is manufactured will become the more evident when its relation to the other parts of the ultimate assembly is considered.

From the welding booth the track roller frames move to assembly. Along a continuous conveyor they take on all the parts except the equalizer spring and pivot shaft, the two members which connect

a right and left frame. The rollers on which the weight of the tractor rests, and their guards are bolted onto the bottom flanges of the channels. The recoil spring with its adjustment, the front idler, with its yoke and guides are all assembled to the frame before it reaches the end of the sub-assembly line. Right and left frames are then paired, the pivot shaft is placed through the seals and bearings in the frame, fastened in place, and lubricated. The equalizer spring assembly is placed in position, and the joined frames await the addition of their motive power. A few moments later the tractor is affixed to the frames, started and driven under its own power onto the extended track. Closing the open link in the track releases the machine to inspection and to test.

As the tractor rolls onto its track, another will take its place over the frame assembly. There can be no misalignment or skewness when parts flow to this tempo. The crane operator and workmen know the parts will go together with the smooth easiness of precision parts, that the new tractor will roll away confidently to a successful test over its self laid track. There is production of heavy machinery!

Summary.—Early in this paper it was stated that an attempt would be made to show why we consider welding a distinct production tool, like any other process not universally applicable, but always worthy of consideration, and possessing many advantages where it can be applied properly. Through a description of the design requirements of a track roller frame assembly, of the methods by which we assure ourselves of uniformity and high quality in welded products, as well as the production and assembly of this frame, these important points have been emphasized. A comprehensive treatment of all of the considerations which justifiably enter the design of a part intended for a long useful life can only point to advantages in the use of welding when the process is applicable.

The dollar cost to the manufacturer has not been emphasized in this paper because it is not of prime importance to this organization as is the excellent and prolonged performance of its machines. Even so, there is enough evidence given to indicate that the welded design does actually effect a saving in manufacturing cost over any comparable design using no welding—a saving which is in excess of a quarter of a million dollars annually. But by far the greatest cost saving, and the one which is important to the company is that continuous saving of human toil and time which the use of the best design in this type of equipment can bring about.

It is significant to recall that tractors tread more different parts of the earth than any other land vehicle; that they regularly work in many remote places where few men and no other locomotive vehicles have ever entered before; that they have been flown to work in localities closed to other types of travel; and that their uses in the civilized world are numerous, widespread, important. In all of these applications the consistent reliability and the effective power of these machines effect an inestimable saving. So also do the uniformly reliable all-welded track roller frame assemblies on which the machines work.

Chapter VIII—Savings Made by Arc Welding in Tractor Construction

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In submitting this paper I shall confine myself chiefly to the savings effected in dollars and cents through changing the design of some of the parts of our tractor so that they could be made by the arc welding process; for, in the final analysis, the manufacturer is more interested in money saved than he is in the purely technical subject of engineering design, strength of material, type of welds, etc.

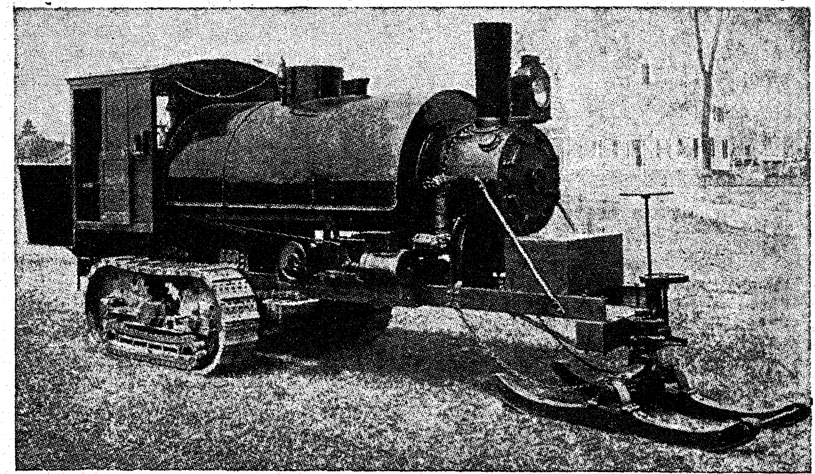

Fig. 1. An early model steam-engined log hauler.

In the year 1900 Mr. A. O. Lombard, with the assistance of his brother, Mr. S. W. Lombard, conceived the idea of and built the first machine that was then known as the Lombard "log hauler." Fig. 1 shows one of these early machines and Fig. 2 the 1938 model.

The changes since the construction of the first machine have been many and varied, such as the change from the slow speed, heavy weight, steam engine to the compact, light weight, high speed, gasoline engine, and later to the more economical diesel engine; from cumbersome cast iron to light weight, high tensile strength, steel castings; from the low grade wrought iron and low carbon steel shafts of that period to the high grade nickel and chrome nickel alloys of the present day; and last, but not by any means least, the change to the arc welding method of fabrication.

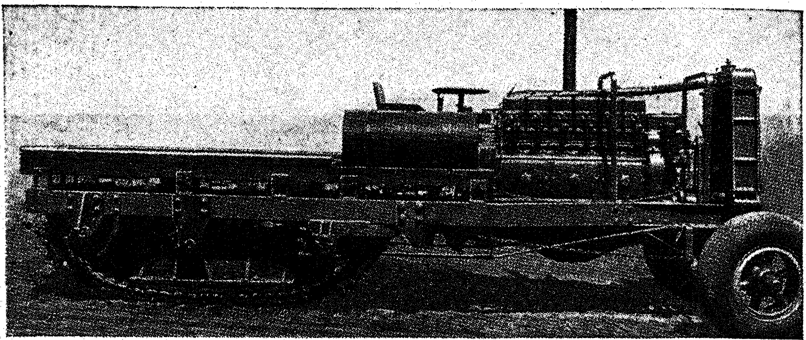

Fig. 2. Modern log hauler which utilizes arc welded construction.

Beginning with steering drum shaft hanger, Fig. 3, this part was previously made from cast iron, and it was necessary to machine the surface that came in contact with the tractor frame at the point where the $3^{33}/_{64}''$ holes are located, also at the lower end of the hanger which is a bearing for the steering shaft. The weight of this casting was $14\frac{1}{3}$ lbs., and cost $6.96 each finished. By using a locating jig while welding together the back plate, which is cut to shape from a $\frac{3}{8}''$ steel plate, and a piece of $1\frac{1}{2}''$ outside diameter, 22 gauge mechanical steel tubing for the shaft bearing, a unit is made that eliminates all machine work except drilling the holes. The cost of the welded part is divided as follows:

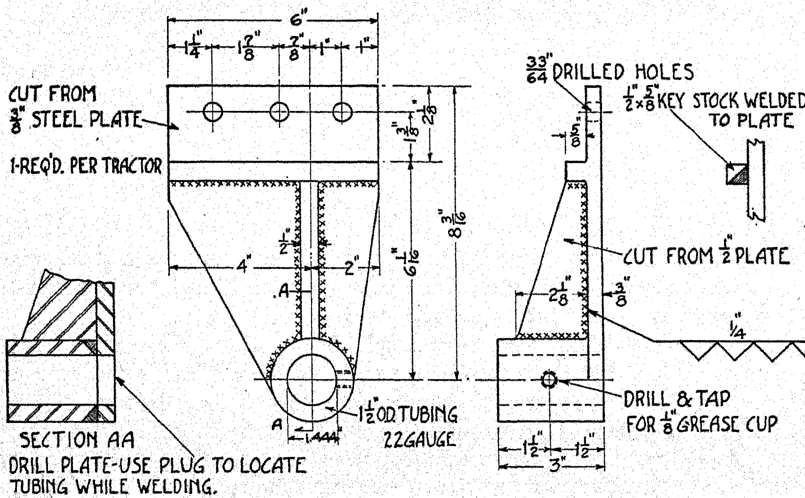

Fig. 3. Steering drum shaft hanger, arc welded at $4.78 saving.

Material, including welding-rod and gas for flame cutting	Time cutting, assembling and drilling, 1 hour	Welding
$ .38	$1.20	$ .60

Total cost $2.18
Saving over cast unit $4.78
Saving per tractor $4.78

The use of steel tubing as a bearing, without being machined or bushed with some conventional bearing material, is permissible in the construction of the above unit as well as others to be described later, because the movement of the shaft is very slow and intermittent such as that caused by hand steering or the partial turning of the load-carrying unit or runner on the shaft due to the unevenness of the ground over which the tractor travels.

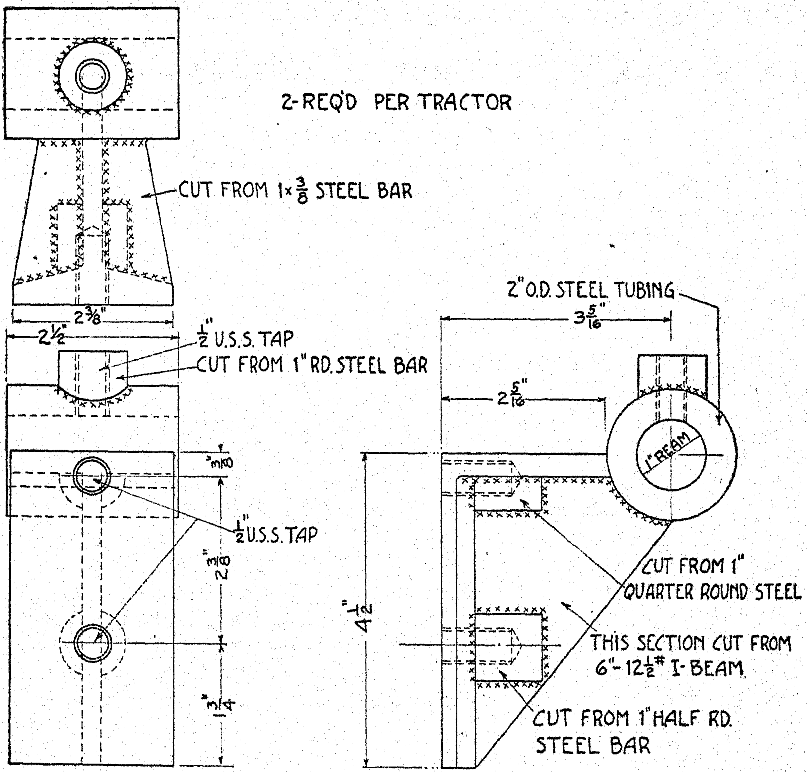

Fig. 4. Clutch throw-out shaft bearing, arc welded at $1.58 saving.

The clutch throwout shaft bearing is, as the title indicates, a bearing or support for the shaft that actuates the clutch release. There are two of these units required per tractor. They were made of cast iron at a cost of $1.80 each. They were machined on the surface where they come in contact with the frame, also at the point where the shaft passes through. By substituting a piece of 6″-12.5 # I beam for the

base and a piece of 2″ O. D. 1/2 wall steel tubing for the bearing, all machine work is eliminated except the drilling and a 1″ reamer passed through the hole for the shaft. Cost of welded part:

Material including gas and welding rod	Fitting and Assembling 1/2 hour	Welding 1/6 hour
$ .22	$ .60	$ .20

Cost each $1.02
Cost per tractor $2.04
Saving per tractor $1.58

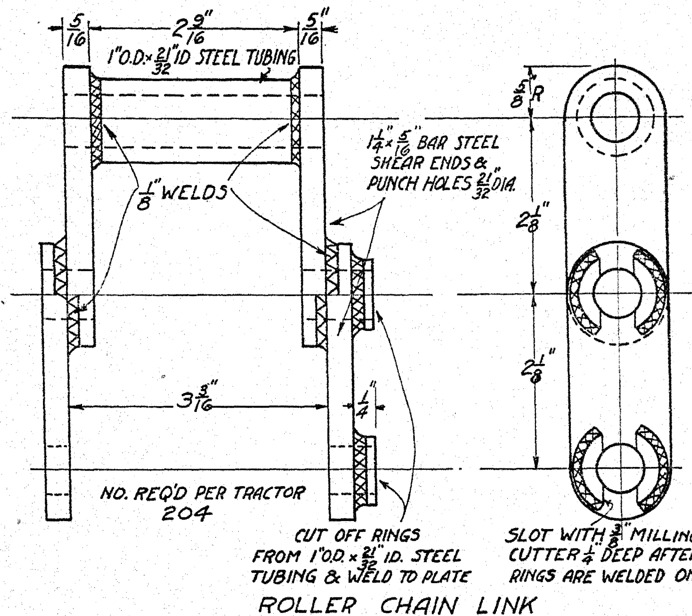

Fig. 5. Roller chain links, arc welded, save $22.44 per tractor.

There are 204 roller chain links required per tractor. These links are assembled with hardened steel rollers to make up the roller chains that are used between the load-carrying unit and treads that come in contact with the ground. The function of these chains is to continually lay down new rollers for the tractor to roll on as the drive sprockets revolve and force the tractor forward or backward. These links have for years been made from drop forgings and, drilled under a three spindle drill. This method is a comparatively expensive drilling operation as two of the drills are out of the cut about 60% of the time. The cost of the links each made from forgings was $ .44, or $89.76 per tractor.

Substituting the arc welding process of fabrication, we cut four pieces of 5/16″ x 1 1/4″ bar steel to length, shear the ends and punch 21/32″ holes. They are then assembled on a locating and welding jig together with a piece of 1″ O. D. steel tubing having an inside diameter of 21/32″. These parts are then welded. The cost by this method is divided as follows:

Material	Punching, shearing and Assembling 4 min.	Welding 6 min.
$ .13	$ .08	$ .12

Cost each ....$ .33
Cost per tractor $67.32
Saving per tractor $22.44

In addition to the saving on the links, it had become necessary for us to have a new set of forging dies made at a cost of $600 unless we changed to some other method of manufacture. This outlay is now unnecessary. There is also another advantage in this method that we cannot overlook; whereas in the past, it has been necessary for us to carry a large stock of the forgings on hand due to the fact that the price became prohibitive when ordered in small quantities, we can now reduce our inventory to a minimum as we can now make them up in any quantity required from standard stock.

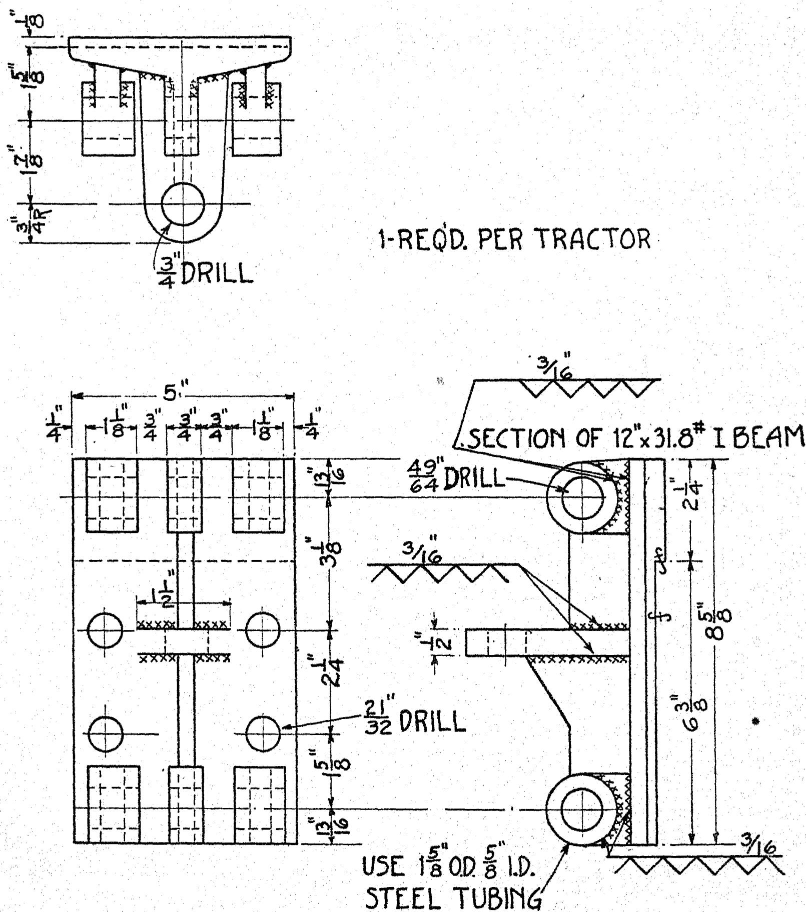

Fig. 6. Base for attachment of brake levers arc welded for two-thirds the cost of a steel casting.

The main brake bell crank was first made from a blacksmith's hand forging and was later changed to a steel casting. The cost of the casting machined was $2.10 each. This was also the cost per tractor as there is only one required. In making the part by welding, we cut a piece of 2″ O. D. by 1¼″ I. D. steel tubing 2½″ long for the hub, thus eliminating all machining at this point. The two arms which are flame-cut to shape are then welded on to the hub 90 degrees apart. The cost of the welded part is:

Material	Time fitting, assembling and drilling, 1/6 hour	Welding 1/12 hour
$ .50	$ .20	$ .10

Cost each .... $ .80
Cost per tractor .... $ .80
Saving per tractor $1.30

In the case of a base to which the levers that actuate the brake shoes are attached, although the welded part costs approximately the same as the one previously made of cast iron, we get a much stronger part at much less weight and at about two-thirds the cost of a steel casting.

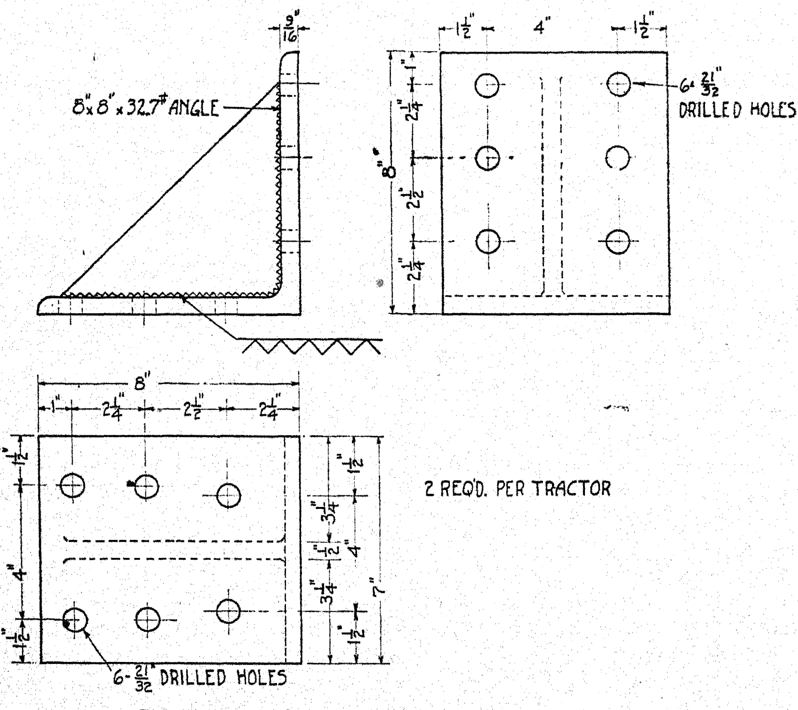

Fig. 7. Arc welded corner angles save $10.02 per tractor.

The load-carrying unit or runner made of cast iron weighed 566 pounds each or 1132 pounds per tractor and cost $43.56 each or $87.12 per tractor. In redesigning for arc welding, all machine work is eliminated by using a piece of steel tubing, of the proper size to fit the shaft,

for the hub and two pieces of ¾" x 4½" bar steel for the base, the base having to be machined when made of a casting, to have it straight enough to align two manganese steel shoes that are bolted on at this point. It is of course necessary in welding up this unit as well as all others where machine work is eliminated, to have a locating and welding fixture which will hold the separate parts in alignment and true to dimension while they are welded to make the complete unit. This unit made by the arc welding process weighs 332 pounds (figured weight) and the cost is divided as follows:

Material	Time cutting, assembling and drilling	Welding
$16.72	4 hours $5.00	5 hours $6.25

Total cost each $27.97
Cost per tractor $55.94
Total saving per tractor $31.18

A corner angle is used to join two sections of the tractor frame. There are two required per tractor. In the past we have made them of steel castings weighing 36 pounds each and costing $6.24 each finished. As redesigned, we use a piece of 8" x 8"-32.7-pound structural angle with a gusset welded in. It is then drilled and performs the same function as the machined steel casting. The cost of the structural angle finished is:

Material	Time fitting gusset, assembling and drilling 1/6 hour	Welding ¼ hour
$ .73	$ .20	$ .30

Total cost each ....$ 1.23
Cost per tractor ....$ 2.46
Total saving per tractor $10.02

The few parts that I have listed are only a small percentage of the number that can be changed advantageously as soon as business conditions warrant the building of more tractors.

All costs are based on the following rates: Labor $1.20 per hour, bar steel and plates $ .045 per lb., steel tubing $ .20 per lb., gas for flame cutting $ .04 per cu. ft., welding rod $ .12 per lb. Cutting, assembling and welding time estimate is based on similar work we are doing each day in our welding department. The total estimated saving per tractor on the six items listed is $71.28 or, for an average year when business is normal, about $2000.00. This of course is not a large sum. However, figuring on a percentage saving basis per item, it will be seen that the savings are in some cases quite large. In every case in figuring costs, welding rod, gas for flame cutting, etc., was considered under the heading of material.

Chapter IX—Redesign of Existing House Trailer To Permit Use of Arc Welding

By Ray F. Kuns,
President, Trotwood Trailers, Inc., Trotwood, Ohio.

Experience gained over a period of eight years in the construction of trailer coaches indicates seven features as being of paramount importance to the user of such equipment. These are: light weight, roominess, close coupling and roadability, rigidity, insulation, economy, and long life. The influence of the new design, Fig. 1, on each of these is discussed briefly in the following paragraphs.

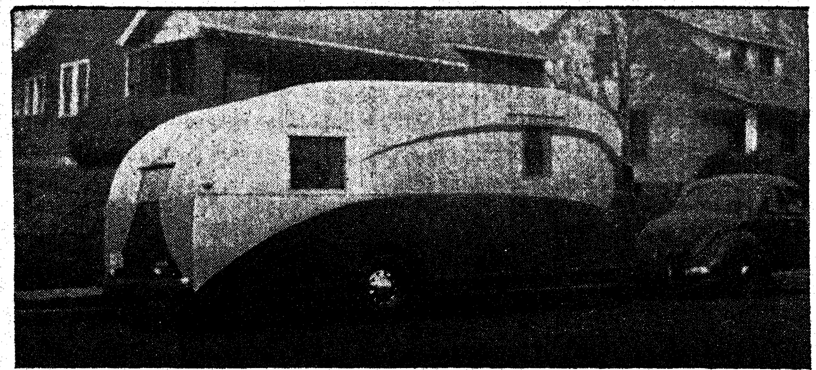

Fig. 1. Modern house trailer built to arc welded design.

Light Weight.—Trailer coaches designed to be used in connection with passenger automobiles should be light weight in order to be easily handled by the ordinary passenger automobile. If they are unduly heavy, the attendant overloading of the passenger vehicle used for towing, results in rapid depreciation of that vehicle and in many cases requires rebuilding of its rear springs. Methods used to secure light weight must not prevent the attainment of the other fundamentals of good trailer coach design. The arc-welded chassis-frame unit allows great strength with light weight because of the truss effect of the sides, which are the weight-carrying members.

Roominess.—Heretofore there has always been need of sacrificing roominess on account of weight factors. This is especially true when the usual form of channel iron is depended on for the weight-carrying frame members. The new design allows greater length and greater strength with less weight.

Close Coupling and Roadability.—On account of legal regulations controlling overall length of the car and trailer, it is desirable to have the forward end of the coach body brought as close to the towing vehicle as practical. Roadability is dependent upon many factors, especially weight distribution, springing, axle location, and frame rigidity. The new design brings the nose of the trailer close to the rear bumper of the tow car and permits good weight distribution.

Rigidity.—Trailer coaches are used on the highways and in camp. A good performance on the highways can be secured only with a rigid frame design which prevents twisting under road shocks and load placement. When used on location, rigidity of frame is essential to prevent misalignment of body and furniture units as weight-shifting strains are induced by movement of the occupants. In the new design, frame misalignment under adverse conditions is prevented by the diagonals, acting both as compression and tension members.

Insulation.—Trailer coaches are used for living purposes in temperatures ranging from below zero to those encountered in desert areas. This means the design must permit of high insulation values with reference to floor, walls, and ceiling to protect against extremes of both heat and cold. "Sweating" is a very real problem. The method of covering and lining described below served to eliminate "sweating" and to secure high insulation values.

Economy.—Trailer coach owners, while demanding roominess and other fundamental factors mentioned, are insistent upon low initial cost and low upkeep. The cost figures on this experimental model show distinct possibilities in economical production.

Long Life.—Long Life is dependent upon a proper selection and use of materials, which, while permitting the meeting of other fundamental requirements, assure the owner of the coach of many years of low-cost service. Experiences had with welded steel airplane fuselages show long life characteristics. Duck coverings on vehicles similar to the design described below show ten to fifteen years of life.

The design by which it is intended to secure to better advantage the seven fundamental features mentioned above is illustrated in Figs. 2, 3, and 4.

The chassis unit used in this new design is identical with previous practice. Short lengths of 3-inch channel are used for the tube mounting E, Fig. 2. Cross members B, of 10-gauge channel, are arc-welded to the ends of the members E. One-eighth- by 1½-inch equal leg angle A is formed and welded to the outer ends of the members B. Thus is formed a housing in which the steel fenders of standard design are mounted and arc welded in place.

Since this job was designed to have a covering of duck, the sill plates B, of modified channel form, were made from 18-gauge hot-rolled sheet metal. The flange formed on the upper leg of the channel is designed to receive and hold the outer covering of the trailer.

Cross sills to support the floor are 3-inch channel of 18-gauge metal. The posts A, Fig. 3, are of Z-form from the 18-gauge metal. These

are placed in such a manner that the drop-type windows may be installed without any additional framing. The same material is used for the rails between the posts at the window line.

Likewise, rafters are made from 1 by 1½ by 1 Z-form metal of 18-gauge.

The most important units in this design are the longerons C, Fig. 2, these being made from 1¼-inch 18-gauge 1020 seamless steel tubing. It will be noted that these two tubes are formed to rise vertically to the window line at the nose, Figs. 3 and 4, at which point they separate and run in the plane of the side sills to the rearmost corners of the trailer frame. All rafters and posts, as well as some diagonals and rails, are arc welded to these longerons.

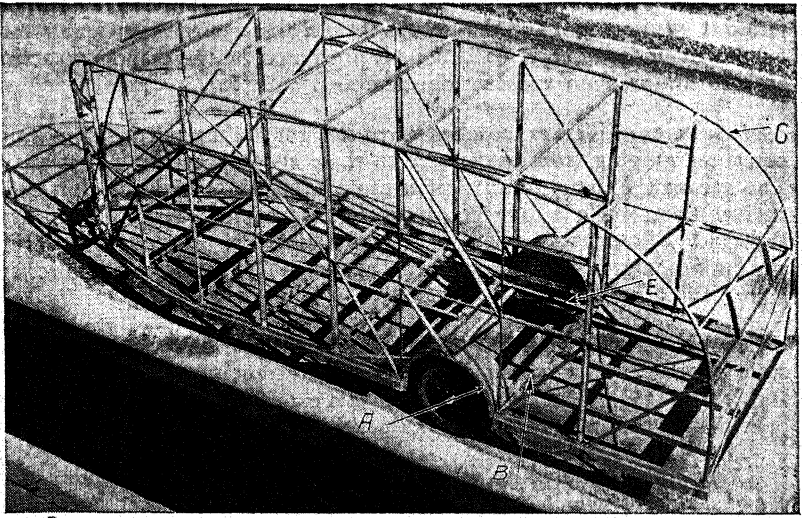

Fig. 2. Arc welded house trailer frame showing use of standard shapes.

In some instances diagonals are made from the Z-metal and in other cases from steel tubing or channels, depending upon location and strains induced. Diagonals on the sides are depended on to give a rigid truss with load-carrying ability. Diagonals at the rear end and over the roof are depended on to prevent any twisting of the frame, which might induce frame wind or misalignment.

Not all diagonals used in the roof are shown in accompanying pictures.

It will be noted that this particular design has most of the characteristics of the tubular fuselage used in airplane design. Great load-carrying characteristics are secured with extremely light weight. The most difficult point to properly truss was point A, Fig. 4, at the door. No sign of sagging at this vital point was in evidence after the road test described in later paragraphs.

Early experiments with this type of design were carried on by means of small scale models, these being constructed from 14-gauge galvanized wire with soldered joints. It was found possible to completely fill the interior of the models with lead shot without any sign of failure when the

model chassis-frame unit was supported in normal manner; that is, at nose and wheel positions.

Other Details of Contruction.—Some details of construction which were necessary in the completion of this experimental unit, shown in Figs. 2, 3, and 4, were: laying the floor, covering the exterior, fitting windows, ventilators and door, lining the interior and installing furniture. No discussion will be given with reference to the furniture, inasmuch as this is of the standard type and involves no new design.

Frames for ventilators were arc welded in position before covering. The exterior of the entire welded frame first was covered with chicken wire netting of 2-inch mesh, this being attached by means of 16-gauge soft iron galvanized wire. The exterior surface next was covered by means of jute. This has very desirable insulating characteristics. The next step was to lay out the duck covering. Three pieces of duck were cut to form, one for each side and another for the roof and rear section. These three sections then were sewed up to form one large bag or envelope, which was then brought down over the trailer frame and stretched from the bottom. The only fastening required for this was that necessary to secure the lower edges and the openings around the windows, door, and ventilator. All raw edges were protected by means of metal mold. It will be seen that the form of the sill B provides a metal unit for protection of the lower edges of the duck covering.

The lining for the interior of the coach is the usual plywood lining, in this case attached by means of metal screws.

Some change from the standard design was necessary in the case of the coupler and third-wheel. Plates were arc welded to the nose of the trailer frame, to which the coupler-and-third-wheel-assembly unit was bolted.

Testing the Completed Trailer.—After completion of the job, it was given a road test from the factory, near Dayton, Ohio, to Everglades, Florida, and return. This initial test covered approximately 2800 miles and served to prove the value of the design. A careful check of the welded structure at vital points, such as the coupler mounting, chassis mounting, bumper mounting, door frame, and other points of greatest strain, showed no indication of failure whatever. The trailer was equipped with normal load for this trip. Cruising speeds were from 45 miles to 75 miles per hour. The longest day's drive was 520 miles. Road conditions encountered were average for winter months. The roadability of the equipment was all that could be asked as there was no tendency to weave or misbehave at any speed attained. Furniture items retained proper alignment and there was no evidence of twisting or misalignment of the trailer frame. Insulation qualities were excellent, as proven by snow and cold in the mountain regions. A gasoline heating unit was utilized and had more than sufficient capacity to maintain the trailer at comfortable temperatures. Tests with a thermometer showed the temperature at a position 6 inches above the floor to be 71 and 6 inches below the ceiling to be 72, with outside temperature below freezing. Although rain, snow, and other winter weather conditions were encountered, at no time was there any evidence of "sweating" on the interior of the trailer. Doubtless, this was

due to the fact that the exterior of the trailer was insulated against rapid temperature changes. Insulation on the floor consisted of the usual plywood flooring, over which two thicknesses of jute were applied, this being protected by means of artificial leather stretched over the floor and tacked at the edges only.

Riding characteristics of the trailer were excellent inasmuch as furniture placed in the trailer without fastening would remain in position throughout a day of driving.

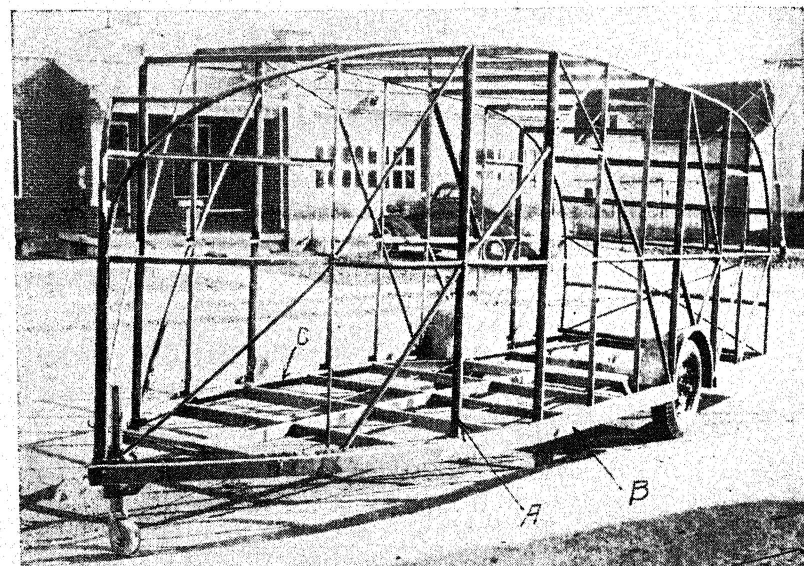

Fig. 3. View of arc welded house trailer frame showing sill plate "B" of modified channel form.

Comparison of New and Old Designs.—It is naturally true that costs of line production cannot be compared fairly with costs of an experimental model, since workmen would not be trained for skill and speed in handling materials of a radically different nature. It also holds that materials purchased in lots for production would be purchased at a great advantage as compared to small lots for an experimental job. Actual production figures for a line production model of comparable size and the arc welded trailer coach chassis-unit frame job are given.

1. Weight—Comparable Floor Area Sizes (Equipped)

Standard Construction	2,920 lbs.
Arc Welded Chassis-Frame Unit	2,174 lbs.
Saving (Weight)	746 lbs.

The saving in weight of the arc welded construction is slightly in excess of 25 per cent. This factor is so vital to the experienced trailer user that he probably would be willing to pay a greater price for a trailer embodying this weight-saving feature than he would pay for a heavier trailer of equal size.

2. Material Cost

Standard Construction	$329.46
Arc Welded Chassis-Frame Unit (Experimental Model)	336.71
Excess (Material Cost)	$ 7.25

These figures show that the cost of the arc welded chassis-frame unit job when completed was slightly greater insofar as the cost of materials was concerned, but, as mentioned previously, materials for the one job were purchased in quantities while materials for the experimental arc welded job were purchased for the one job only. Experience on other experimental models, once they were put into production, indicates that a saving up to 10 per cent of the total cost price could be effected in purchasing materials in quantities for this type of construction.

3. Labor

Standard Construction	300 man-hours
Arc Welded Chassis-Frame Unit (Experimental Model)	756 man-hours
Excess (Labor)	456 man-hours

The standard construction embodies the use of jigs for sides, roof, chassis, and a number of other parts. No time for setting up this equipment is figured in the average 300 man-hours required for the turning out of the standard jobs of comparable size.

On the other hand, the 756 man-hours required for producing the arc welded chassis-frame unit job include all time consumed in the production of the necessary jigs and machinery set up for forming, bending, cutting, and other work which was incidental to this fabrication. Furthermore, it is true that the men doing this preliminary work were the same men who ordinarily handle the wood and plyboard type of construction, so that they were working on materials with which they were not skilled.

The author of this paper has chosen to present the actual time consumed in the production of this one unit and then to estimate possible savings on the experimental job as compared to the cost of producing a quantity of trailers embodying these construction details. For instance, it is safe to assume that at least one third of the total amount of time, namely, 252 man-hours, were spent in setting up machinery, laying out jigs, and making assembly layouts which would not be required in other or additional trailers of this type.

It is furthermore safe to assume that in actual line production the time required for turning out this experimental job could be reduced by one-half of the remaining number of hours, that is, further reduced by 252 hours. Thus it will be safe to assume that the actual construction time required for one of these jobs would be 252 hours.

It is of interest to know that 26 hours was the actual time required of a journeyman welder, one skilled in the art of arc welding, to weld the parts together after they were set in position. In light of this exact figure, the assumed figures mentioned above are likely of proper proportions. The labor saving thus effected would amount to 16 per cent.

Considering the total cost of labor and materials and their relative values, it would seem safe to estimate the total amount of time and

materials saved on the arc welded construction as being about 12 per cent over the standard type of construction.

In the standard type of construction, $135.00 is the average labor cost to produce a job of comparable size to the experimental model. Adding this amount to the $329.46 materials cost gives a figure of $464.46. If the average saving of 12 per cent could be made on a model of this type, it would represent a saving in excess of $55.00 per unit.

The gross saving which could be made to the industry on the basis of this figure is rather difficult to arrive at. In the first place, not all trailers constructed would be this large. Many trailers used for vacations would be approximately two-thirds as large. Naturally, the dollar savings on these smaller units would be somewhat reduced. However, it would be safe to estimate that a saving of from $30.00 to $50.00 could be effected on a line of trailers running from a 16-foot length to a 22-foot length, the size of the model under consideration. It would be safe to assume, then, that an average saving of approximately $40.00 for every trailer manufactured might be saved if this type of construction were to be utilized in the factories throughout the industry.

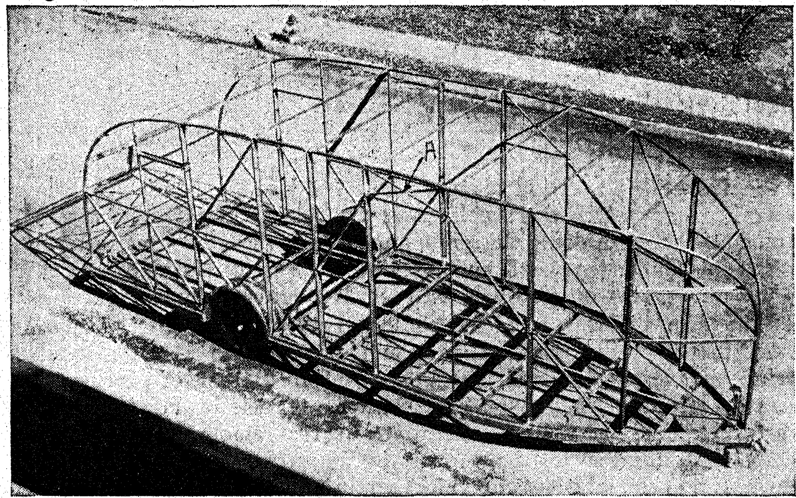

Fig. 4. Trussing at door accomplished by use of arc welded tubing. (See A).

In the matter of an estimate of the actual number of trailers produced per year in the United States, one has to rely somewhat upon the experience and figures of those who have made surveys. These estimates run all the way up to 50,000 and more per year. It is more likely that in the best years, around 35,000 to 40,000 trailer coaches were made and merchandized and that in an average year around 25,000 to 30,000 were produced. On this basis it is estimated that the savings to the industry at large would run approximately $1,000,000 to $1,250,000 yearly.

However, it is not felt that either the saving per unit or the saving to the industry at large has nearly the bearing on the design as has the saving in weight and the general economy and long life of a unit produced

by this method. The social values of this design are set out in detail below when considered with reference to the seven fundamentals of trailer design mentioned in the introduction.

Seven Fundamentals of Design Attained.—The average experienced trailerist desires room in his trailer. However, he always thinks about roominess in connection with weight. From this viewpoint, light weight becomes a determining factor to the experienced trailerist. By saving approximately 25 per cent of the total weight of the completed unit, it is therefore possible to give the trailer purchaser from 20 to 25 per cent more room with the same weight or at the maximum weight which that particular owner is willing to handle.

Light weight assures safety to the person owning the trailer when he is connecting and disconnecting it, as he is less liable to personal injury from handling an over-weight. It also permits him to maneuver his trailer by hand into much more desirable positions than is possible with a trailer which is too heavy for him to handle. It is a distinct aid to him when parking the trailer at home or maneuvering it about the garage. Light weight affords a definite economy to the trailer owner inasmuch as less weight on the draw bar allows the owner to maintain his automobile in its original condition, that is, without the addition of helper springs which cause hard riding when the car is used without the trailer. This, of itself while an economy, is only one of a number of economies insofar as the maintenance of the car is concerned with reference to the weight of the trailer. An extremely heavy trailer is likely to cause rapid wear on the clutch and tires of the car. In some cases extreme overloading of the rear axle of the automobile has caused failure of that unit.

American folks living in trailers are entitled to sufficient room within the trailer to permit of having those conveniences to which they have been accustomed in their usual homes. This means, of course, that there must be room for the bath, the kitchen, dining, living, and sleeping facilities, as well as all of those items of furniture usually required for these operations. While trailer designers have succeeded in producing items which are marvels of efficiency, it still holds that a certain degree of roominess is desired if the trailer owner and user is to be contented and satisfied with his purchase and if it is to give him the large element of health-giving living which he has been led to expect as his right. These ends will surely be defeated if this roominess is secured at the cost of weights which are difficult and dangerous to handle. The arc welded chassis-frame unit's roominess with light weight is to be attained.

The insulation of the trailer unit is an item about which much has been said and which can be proven best by actual experience. Experience in the use of this particular model has been wholly satisfactory both with reference to heating and with reference to keeping it comfortable in the bright sunshine. The prevention of "sweating" is ascribed to the peculiar advantages of the duck-over-jute over the arc welded steel frame, which prevents rapid changes of temperature on the steel framework and serves to make for a dry "sweat-proof" interior. The use of the trailer on the road at the speeds mentioned depended, of course, upon its behaving in a satisfactory manner, which means that it was free from roll, bob, weave, and other features which would make it unsafe.

The rigidity of the welded frame, coupled with the fact that all towing is through steel members welded into one unit, no doubt is accountable for the fact that the performance (roadability) of this unit is quite commendable. The form of the front end of the trailer is such as to allow close coupling of the unit to the automobile, thus giving a desirable and pleasing effect, while at the same time serving to shorten the over-all length of the trailer and car.

The economy of operation and ownership of a trailer is not wholly tied up with the first cost of the unit. Rather, it is dependent upon the adaptability of the unit to conditions under which it is to be used, with the assurance that it will give a long life of carefree service. Maintenance cost of the trailer ought not to be unduly high. With the type of construction embodied in the arc welded trailer coach chassis-frame unit, there is little reason to believe that the structure itself would not serve over a period of from ten to twenty years. On the other hand, past experiences tend to prove that a duck covering properly cared for will give a life of a similar period of time. Actual records are on hand of duck-covered vehicles which are still in good condition although they have been exposed to the weather for periods of more than fifteen years.

Conclusion.—The sole purpose of developing the arc welded chassis-frame unit was to meet a well defined demand on the part of the trailer-using public for a trailer which would meet and satisfy to the greatest possible extent the seven fundamentals as outlined. It is believed it does this. It is further believed that experience in line production will show the use of arc welding a means of saving 12 per cent on labor and materials. It is further believed that the savings to the industry can be in excess of $1,000,000 yearly.

SECTION II

AIRCRAFT

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SECTION II
AIRCRAFT

Chapter I—Arc Welding in Aircraft Heating

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Importance of Aircraft Heating.—With the advent of air travel as a commonplace medium of transportation, it was readily realized that passenger comfort was second only to passenger safety, a fact that is now universally recognized by all forms of transportation. Due to the fact that air transportation was a new industry and had to defeat already established competitive transportation, it was supremely important that air transportation offer unsurpassed comfort to its passengers, and every effort is being made to accomplish this.

There are many items which contribute to the comfort of air travel and one of the prime and possibly the most important item is the heating of the cockpit and cabin. This heating is a year around necessity, being used regularly in the winter and intermittently in the summer. It is not uncommon to encounter five or ten degree weather at high altitudes when the temperature on the ground is ninety-five or one hundred degrees above zero and for that reason it is necessary to have the heating system in operating condition all the year.

As an example of the emphasis placed on the heating of airplanes, American Airlines recently spent approximately $55,000 for the purchase of air-conditioner truck units to be used to heat or cool the airplanes at the terminals for the few minutes that the passengers are in the ship prior to the takeoff, after which the airplane's heating and ventilation system effects the operation. Other operators have adopted this procedure and have no doubt invested comparative amounts in such units.

An additional precaution was taken by American Airlines in the form of purchasing blankets to be carried on the airplanes and to be used in event of heating system failure. This represented an expenditure of approximately $10,000 plus the loss in revenue due to the additional weight carried.

The heating of airplanes is, of course, not confined to passenger airplanes but is necessary to military aircraft as well. Without heat there would be occasions when conditions were such that it would be impossible for the human body to properly function due to the intense cold. It is apparent that this would seriously limit the effectiveness of what promises to be the most important branch of our national defense.

Also the heating of private airplanes is not to be ignored in view of the ever-increasing popularity of this form of travel. Most of the late model private airplanes are delivered equipped with heating systems and there are several types of systems available for those not so equipped.

Methods of Heating.—Any system adopted to effect this heating operation must first of all be safe and must also be dependable, efficient, lightweight and easily controlled. In view of these requirements, many types of heating systems have been thoroughly investigated and the list of possibilities pared down to the two most promising types; namely, hot air heating and steam heating. Both types have undergone extensive theoretical and practical investigation the past three or four years.

In the use of the hot air system, outside air is heated by being passed in the immediate vicinity of the engine exhaust system which consists of an arrangement of tubular manifolds and stacks. The heated air is then passed into the cabin through suitable ventilation ducts so arranged as to give the desired distribution of heat.

The hot-air system is inherently unsafe and has been practically abandoned by the aircraft manufacturers within the past few years excepting in some very small airplanes.

The danger in this method is due to the fact that the air is of a necessity passed so near the engine exhaust system in order to be heated that any crack or failure of any of the numerous exhaust stacks or manifolds will introduce exhaust gases, including the dreaded carbon monoxide into the passenger cabin incoming air. Since failures in the exhaust system occur frequently due to the intense heat and vibration, it is quite apparent that the hot air system of heating is unsafe.

The principal advantage of the hot air system is that it is light in weight; however, the advantages so gained do not offset the disadvantages so as to make its use advisable. Safety is never sacrificed for weight efficiency in the design of aircraft.

The steam heating system is fundamentally much more adaptable due to its safety, ease of control, and its ability to furnish clean fresh air at any temperature.

In order to familiarize the reader with the actual problems involved, the authors will explain briefly the installation and operation of the ventilation and steam heating system of a modern airliner.

Refer to Fig. 1 for a perspective view of a modern airliner, the Douglas DC-3 or DST,* showing the ventilation and heating system and to Fig. 2 for a schematic piping diagram of the heating system.

To effect the ventilation operation, the cabin air is obtained by forcing outside air through an air supply duct from the nose of the airplane. The quantity is regulated by a flap type valve located at the forward end of the duct. The valve is manually controlled from the cockpit. The outside air is forced through this duct by the air "ram" due to the forward motion of the airplane and passes through this supply duct to the steam radiator at which point it either passes through the radiator and is heated, or passes around the radiator, depending upon the demand for heat in the cabin. From this point the air is conveyed to a mixing chamber and then to the cabin where it is distributed by means of a warm air duct which runs along the floor line beneath the seats on either side of the cabin.

Cold air for summer cooling or individual temperature regulation is furnished to the cabin through two cold air ducts which extend

* Sleeper version of DC-3.

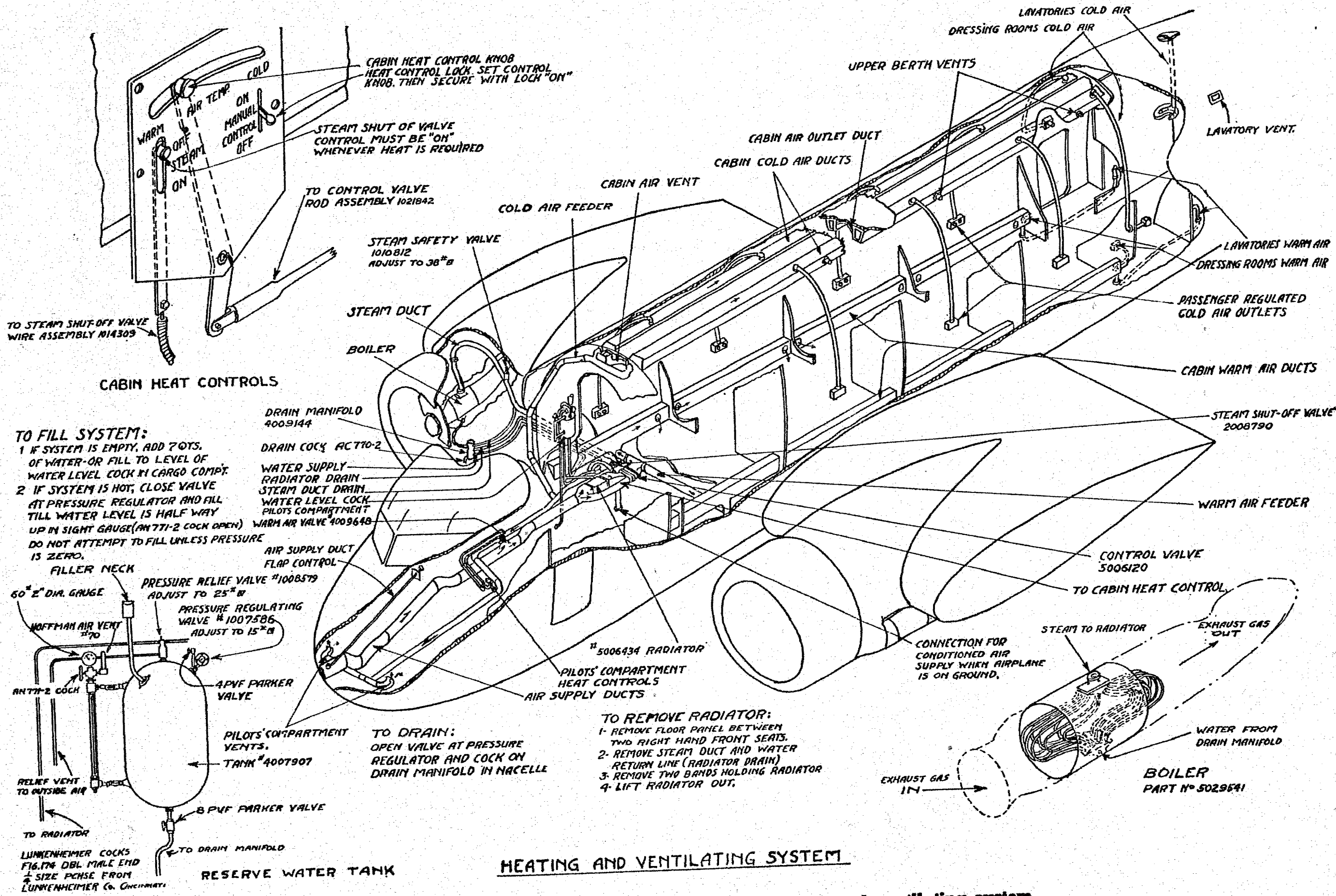

Fig. 1. Perspective drawing of airplane showing heating and ventilating system.

the full length of the cabin just above the windows. The cold air supply is taken from the main outside air supply duct at a point just forward of the radiator.

There are two adjustable air outlet louvres in the cabin ceiling to exhaust stale air. These are so located as to provide efficient stale air exit without producing drafts or uneven temperature conditions.

The system includes the necessary control valves and individual outlets to afford individual comfort and the capacity of the system is such that the entire cabin air (1200 cu. ft.) can be changed in approximately one minute (cruising speed of 180 miles per hour).

The heating system as shown in Fig. 1 consists essentially of a boiler in the exhaust stack of the right engine, a radiator in the air supply duct, a reserve water supply tank in the right cargo compartment, and the necessary valves and controls to effect a safe and efficient heating operation. The boiler operates as a dry boiler, admitting water only when there is a demand for steam in the radiator. Under normal operation, the radiator is always full of steam and the reserve water tank supplies water to the boiler as needed to maintain the steam in the radiator. As the steam in the radiator gives up its heat to the air flowing through the radiator, the steam is condensed and flows back to the boiler.

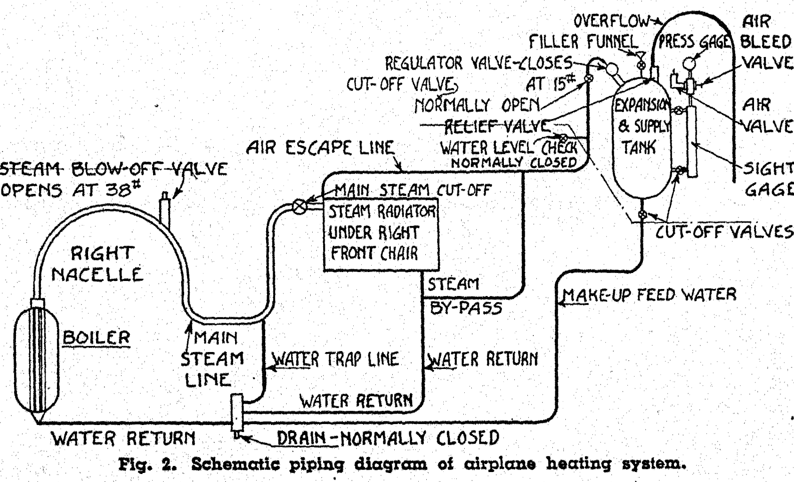

Fig. 2. Schematic piping diagram of airplane heating system.

There is a thermostatic and a manual control in the cabin, either of which can be adjusted by the stewardess to obtain the desired cabin temperature.

It is quite apparent that the boiler is the very "heart" of the heating and ventilating system. A failure of the boiler will immediately cause the entire system to be inoperative thereby resulting in an uncomfortable and sometimes an unbearable temperature condition in the cabin.

Refer to Figs. 3, 4, and 5 for views of the bare boiler units. Figs. 4 and 5 include the Douglas DC-2 "S" shaped boiler units which are not included in this report. The DC-2 boilers have also given improved service due to the application of arc welding. A proportionate saving has been effected in the manufacture of the DC-2 boilers using the arc welder but this paper is written on DST and DC-3 boilers only. Fig. 3 illustrates the Douglas DC-3 boiler unit complete with upper and lower sumps and Fig. 6 illustrates the Douglas DC-3 boiler complete (shell and unit).

Troubles Experienced.—The design of this system was very good and the cabins were furnished with a bountiful supply of clean pure air and at the proper temperatures. From all appearances, the airplane heating problems were solved by this system when it was put into commercial use on the Douglas DC-2 airplanes in 1934 and later on the DST and DC-3 airplanes, but after the airplanes were operated a short time it was found that the heating system boilers were failing in an unreasonably short time, the first ones only lasting from ten to fifteen flying hours. The failures ranged from complete burning out of the outside shell which exposed the airplane to a fire hazard to the failing of one or two tubes which resulted in a loss of the water in the system. This inability to construct a boiler that would withstand the vibration and intense heat threatened the very existence of what had promised to be the solution to the heating problem.

The conditions under which the boiler operates are very severe. One of the most serious conditions is that of expansion and contraction of the boiler tubes. The airplane may be parked on a ramp with its engines running thereby subjecting the boiler to intense heat with no heat being removed due to the fact that there is no "ram" forcing air into the nose duct. A few minutes later the same plane may be flying at altitude at a low temperature and with normal heat being removed from the boiler to heat the cabin air. Within a very short time the same ship may be again parked on a ramp in another city without the engines running and with the outside air at a low temperature. Of course the boiler units cool off very quickly. The operation affords a cycle of quickly applied heat, normal heated operation, and back to a rapid cooling condition, all of which impose extreme expansive and contractive conditions on the metal.

Also the unit operates both as a wet system and as a dry system. It is a wet system until enough steam is generated to build up a back pressure sufficient to stop the flow of water. The water that is then in the lines cools off rapidly and as soon as the pressure drops, it flows into the boiler, thereby imposing a severe quenching condition on the metal which tends to harden the tubes and make them brittle.

The above conditions are supplemented by an extreme vibration condition due partially to the fact that the boiler is mounted onto the exhaust stack which is in turn mounted on the engine. This vibration is also augmented by the fact that often the boiler tubes set up vibration periods which are in phase with the engine vibration.

From this discussion it is apparent that the boiler must operate under very severe conditions which include a great amount of ex-

pansion, contraction, and vibration together with a cold water quenching action. In view of these requirements it is realized that the development of a satisfactory boiler was no small matter.

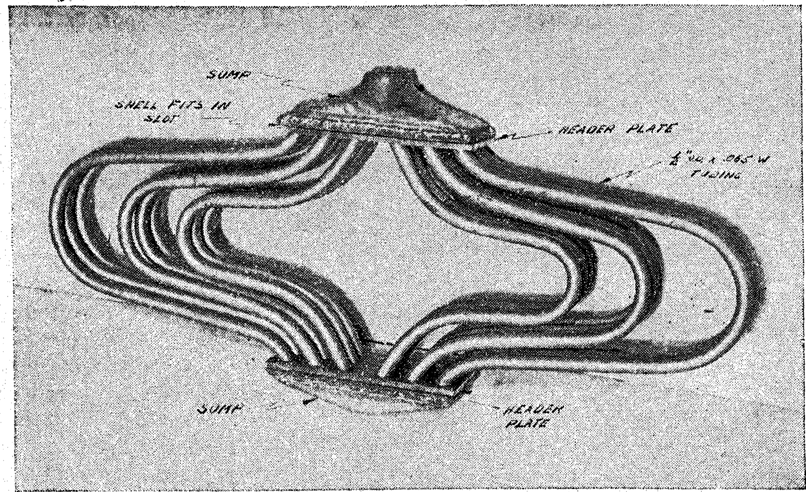

Fig. 3. Arc welded boiler unit of airplane heater.

Steps Toward Improvements.—Innumerable aircraft manufacturers, companies skilled in such work, and learned individuals worked diligently for about three years exhausting every conceivable design and every known type of metal in an effort to prolong the life of the heating system boiler.

The first approach to the problem was that of changing the material of which the unit was made. Service tests were conducted over a period of approximately two years during which time every conceivable heat resisting metal and alloy that was adaptable was tested both in laboratories and in actual installations. American Airlines has records of service test installations of at least fifteen boilers, each of a different material.

The second approach was that of changing the design of the boiler. Several companies went to a great deal of expense to construct units of entirely different designs. Among these designs were several "water jacket" types which substituted a water compartment around the exhaust pipe for the tubular section as was standard. Other designs included "single tube" boilers consisting of one long tube mounted in the exhaust section. The majority of these designs met defeat in their inability to provide sufficient heat, which is roughly proportionate to the area exposed to the exhaust flame.

Two facts of particular interest were established by this experimenting. One was that the tubular boiler shown in Fig. 6 was the only type boiler that had sufficient capacity to provide the required heat. The second fact was that titanium-stabilized 18-8 stainless steel would give the longest service.

Some difficulty had previously been experienced with the welding of stainless steels, especially where used under high temperature and extreme vibration conditions. Apparently the chromium was depleted due to a formation of chromium carbide by a combining of the chromium with the carbon in solution in the steel, often aided and abetted by the carbon in the welding flame. This was partially brought under control by carefully guarding the maximum of carbon content and by the addition of titanium to the alloy. The titanium forms harmless carbides in preference to the chromium carbide. This condition is not so critical in arc welding due to the localized heat and due to the short time that the material is at the welding temperature. In view of these facts and the service records, titanium-stabilized 18-8 stainless steel is still used in the construction of the boilers throughout.

Improvements were noted as a result of service testing and redesigning, but in spite of these improvements, up until the summer of 1937, American Airline's boilers, which were of the latest type, were only averaging a mere seventy-five (75) hours on DST and DC-3 airplanes. Most operators were getting even less service due to the use of different type power plants with higher exhaust heat characteristics.

The boilers were being purchased from the aircraft manufacturer for approximately \$195 each and could be repaired on an average of four times before being destroyed. Each repair cost approximately \$20 including material and time required to remove the unit and to install a serviceable unit. This totaled \$275 for five service periods or \$55 per 75-hour period.

American Airlines schedules their fleet of 30 DST and DC-3 airplanes an average of 215 flying hours per day. Dividing this by the average boiler life period of 75 hours, we find that this company alone was experiencing an average of 2.87 boiler failures per day costing \$157.85 per day for heating system boilers alone. This totals approximately \$57,600 per year for this one operation on only 30 planes.

This cost seems unreasonable and exorbitant but it is merely the tangible cost of the boiler in the heating of the airplanes. The real cost, which unfortunately for the purposes of this paper is more or less intangible, is the unfavorable passenger reactions caused by uncomfortably heated trips.

Assuming the average flight to be four hours, which is a close approximation, the average boiler life of 75 hours means that there was a boiler failure approximately every nineteenth flight resulting in an uncomfortable trip. This resulted in approximately 5.3% of the total number of the passengers having an uncomfortable trip due to boiler failures alone, and as a result of the trip becoming very definitely potential non-air travelers in the future.

During the winter of 1936-37 the superintendent of maintenance received an average of forty trouble reports a month from field stations concerning interrupted flights, station delays and passenger complaints due to boiler failures or erratic operation.

The loss of the 5.3% of the passengers plus the number of people that might have become passengers had they not heard of the discomfort that sometimes prevailed, threatened the very existence of air travel.

The changes in material and slight changes in design had practically eliminated failures of all parts of the boiler except those failures of the boiler tubes. Failures in this region were by far the most prevalent and were occuring, as has been mentioned, on an average of every seventy-five hours. In view of this fact, American Airlines naturally decided to concentrate on the tubular section.

As will be noted from Fig. 4, the method of fabrication is to bend the ½" D.X.065 W. stainless steel tubing into shape and to bring the tubing ends through the ⅜" header plates. The tubing ends protrude on the opposite side for approximately ⅛". The tubes are then welded to the top side of the header plate in somewhat of a rosette fashion, burning off the ⅛" protrusion of the tubing. The weld starts out as a fillet weld but actually developes into a corner weld. The sumps are then welded into position on the header plates.

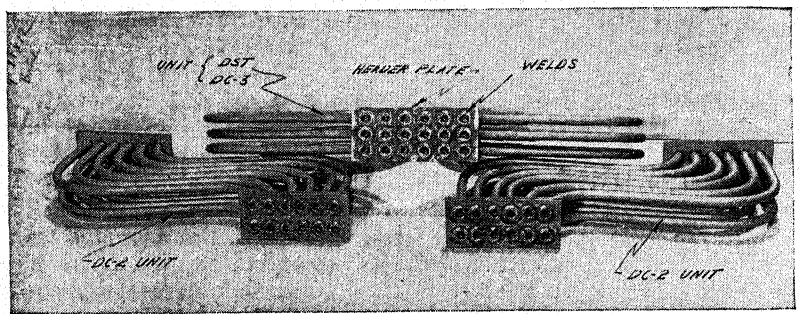

Fig. 4. Arc welded boiler units, showing welds joining tubes to header.

Due to differences in the thickness of the materials it was necessary, with the former method of fabrication, to preheat the lower side of the header plates while the tubes were welded on the other side. This procedure resulted in the ends of the boiler tubing being brought to a very high temperature and also necessitated two men to construct one boiler. It was also noted that there was a very high carbide precipitate when welded in this manner.

After welding, the unit is subjected to internal air pressure and submerged in water to test for leaks. Due to the inconsistency of the welds made by the former method, it was not uncommon to reweld a boiler seven or eight times before a satisfactory test was obtained. Of course, each time a boiler was rewelded, it was reheated, which took time and labor, and was detrimental to the metal.

Through close observation of boilers which failed in the field and which were returned, the authors noted that the majority of failures occurred in the form of a crack extending completely around a boiler tube in the immediate vicinity of the welds which also is in a section

of the tubing bend. The authors, together with other members of the company, formed the theory that the intense heat subjected to the tubes and header plates in the former welding process was supplementary to the already-induced bending stresses and thereby formed a distortion to the metal fibres which when aggravated by the vibration, contraction, expansion and quenching conditions, would cause a breakdown. In other words, in heating the ends of the tubes and the header plates to the almost red heat necessary to effect the former type of welding, and due to the subsequent irregular cooling, the material was subjected to internal stresses under which no material could possibly give service especially when accompanied by such severe additional conditions.

At about the same time, which was in the late summer of 1937, the authors having some knowledge of the merits of arc welding, were very pleased to learn that arrangements were being made with a large welding equipment manufacturer to install a 150-ampere machine on approval. The machine was to be used for general maintenance repairs to jigs, machinery, ground equipment, and items not directly connected with aircraft.

Soon after observing the arc welder work, and after learning more about its principal and its results, it was believed that this was the solution to our boiler problem due to the fact that the heat was very definitely localized. If our previous theory of extreme heat distorting the metal was correct, the arc welder should be the answer to the problem.

Soon after the machine was delivered, the authors began conducting some simple, practical tests to determine more about the practicability of this process for our use in boiler construction. One of these simple tests consisted of welding four short pieces of tubing into a header plate in the usual manner. Two were arc welded and two were welded by the former process. The assembly was then placed in a hydraulic press in such a manner as to give a direct end load on the short pieces of tubing and a subsequent shear load on the weld. The two tubes welded by the former method sheared off at the weld, one under 2½ tons and the other under 3½ tons pressure. The two arc welded tubes were loaded to 8½ tons pressure at which load the walls of the tubing collapsed while the welds were unaffected.

Several examples of the arc welds were sent to different laboratories for analysis to determine if our theory was correct; but due to delay in getting this analysis, we requested permission from the supervision to build one boiler for service tests, using the arc welder.

A supply of stainless steel arc welding electrode was obtained, and using the standard jigs and materials, the first boiler was welded in forty minutes, (see Fig. 7). One small pin hole leak was found when the boiler was tested. This was easily repaired, and the total time for welding, testing, and repairing was exactly one hour against eight hours for the previously used welding process.

In addition to the using of arc welding on this first unit, it was decided to decrease the angle at which the tubes entered the header plates. This was decreased from ninety degrees to sixty degrees by drilling the header plate holes on an angle. This would tend to decrease the bending stresses induced by the bending operation.

The first boiler was put into service soon thereafter, and operated continuously without repairs for a total of 420 hours, which was very gratifying in view of the 10 and 15-hour periods of the first factory experimental boilers, and the actual average of 75 hours on later boilers.

We were reasonably certain that we had found the solution, and that it was arc welding. Therefore, as soon as possible, we constructed fifty more boilers in the same manner for service tests to further substantiate our beliefs. These fifty boilers averaged 376 hours of

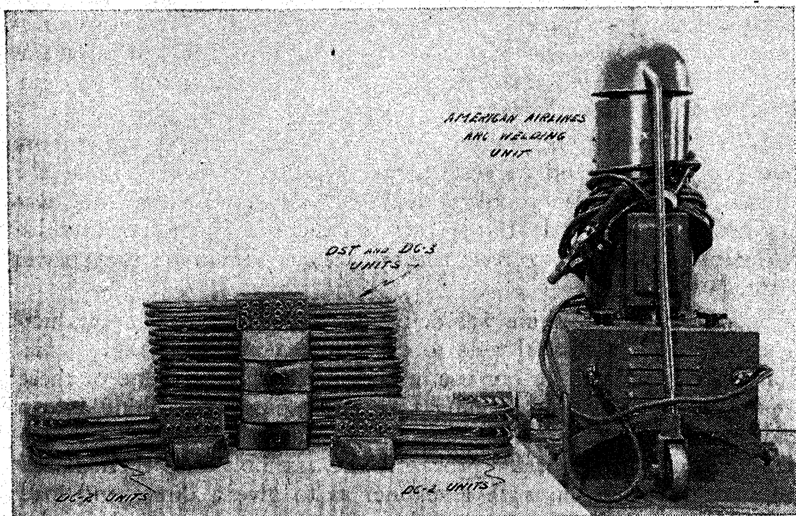

Fig. 5. Arc welded airplane boiler units. Note S-shaped units.

flying which was certainly a great improvement over the previous average of 75 hours.

In view of these very encouraging service tests, American Airlines immediately began production of the arc welded boilers and instigated a program in the fall of 1937 to replace all of the factory-made boilers with arc welded boilers.

We felt that with a little experience we could improve our technique and cut our costs to the extent that we could safely and economically operate our boilers for an engine change period (450 hours) and then obsolete the unit. In this way we could experience no failures excepting an occasional discrepancy due to faulty material that could not be determined on inspection prior to assembly.

Results Accomplished.—In addition to the actual monetary savings which will be shown later, the service of the boiler was improved to the extent that during the winter of 1937-1938, the superintendent of maintenance received an average of only 13 trouble reports a month as compared to an average of 40 per month for the previous winter. Part of these 13 trouble reports were due to the old type boilers that had not yet been replaced due to our inability to manufacture sufficient boilers to make a complete change at one time. To this date not one boiler has failed because of tubular breakdown adjacent to the weld, as was prevalent before arc welding was adopted. This improved service was of inestimable value from the passenger reaction standpoint, and American Airlines built up a nation-wide reputation as being the only company to have the heating system problems solved.

In a spirit of co-operation, American Airlines furnished drawings and sample boilers to four of its largest competitors, and to the United

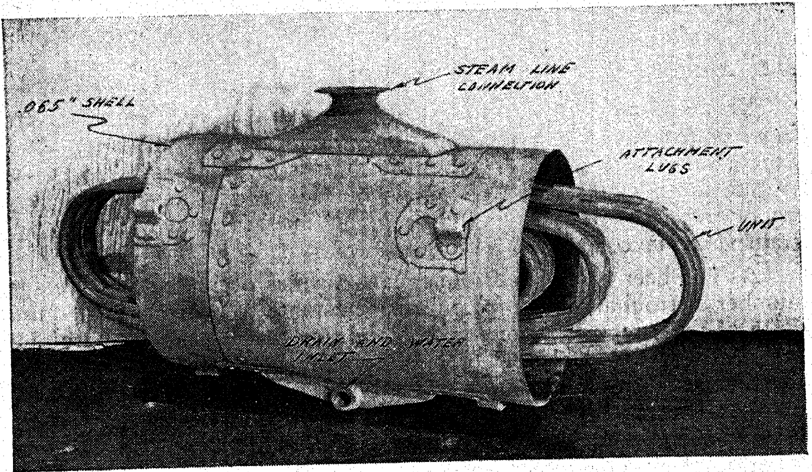

Fig. 6. Airplane heating boiler, complete with shell and arc welded unit.

States war department. It is our understanding at the present time that the army, navy, and at least four of the nation's largest airlines intend to use arc welding in the construction of these boilers. Drawings were also furnished to Douglas Aircraft Company, the designer and manufacturer of the original boiler. It is our understanding at the time of the writing of this paper, that Douglas Aircraft has gone into production on the American Airlines type boiler, using arc welding. The price quoted is $125 each instead of the former price of approximately $195 for practically the same boiler except welded by the old method. This decrease in price is no doubt due primarily to the decrease in man-hours required by the arc welding process and also to the possibility of a competitive field being established due to American Airlines success with the arc welding process.

Having learned something of the potential possibilities of arc welding, we intend to next apply its use to the manufacture of engine exhaust manifolds and anticipate as great, if not a greater, saving in the manufacture of these units. At the present time, this company is spending an average of $600 per month for exhaust manifolds, and if the service time on the arc welded unit that we now have installed is any criterion of its qualities, we can lower this cost to a mere fraction of what it is at present.

In addition to the use of our arc welding equipment for the above mentioned purposes, we have benefitted by its use on many miscellaneous repair projects not directly connected with airplanes, and are able to foresee its use in many more. For the sake of brevity, however, mention of these items will be excluded from this report.

Savings Accomplished.—Economic gains that are accredited to the use of arc welding in the manufacture of airplane heating system boilers might be divided into two classes, namely:

1. Improved passenger comfort and its subsequent favorable reactions resulting in increased passenger traffic.
2. Actual monetary savings in the construction of boiler units.

The economical accomplishments in regard to the first class are more or less intangible, and could only be estimated over a period of time taking cognizance of other business conditions that might attribute to an increase or decrease in business. It is, however, a very important accomplishment, and is given much consideration by all transportation companies.

As has been mentioned, American Airlines decreased the average number of trouble reports from forty per month to thirteen per month. Each of these reports represented a condition that was a self-energized, self-propagated "whirlpool" of public sentiment. Each passenger who experiences a cold trip almost invariably relates his or her experience to some friend who in turn passes this unfavorable report on to some other person in the course of conversation. This continues and over a period of time definitely affects air traffic.

This average of thirteen reports per month even included a portion of the winter in which some of the old-type boilers were still in service. Even so, the number represents a substantial saving and during the past winter, American Airlines has enjoyed an indisputable reputation of having afforded the very best in passenger comfort and the use of arc welding has been the outstanding contributory factor.

As previously mentioned, the factory price to the operators on the complete boiler is approximately $195 each. The cost tables given later show that the same boiler was built in American Airlines shops for $84.08 each using the former welding process and for $53.47 each using the arc welding process. The later two prices do not include overhead as the post office department requires that supervisory costs be carried in expense accounts. For this reason the authors have no definite figure for the overhead costs for this company but assuming 100% overhead which we understand is general practice and is a reasonable

figure, the cost of the previous boiler is $168.16 each and the cost of the shop-made arc welded boiler is $106.94 each.

As has already been shown, heating system boilers for thirty airplanes were costing American Airlines $57,600.00 per year when purchased from the factory and on the basis of 75 hours service life. This amounts to $1920 per airplane per year. There are at the present time 194 airplanes of this type in service and assuming the average boiler service for all the airplanes of this type to be the same as that of American Airlines, the industry was spending $372,480 per year for heating system boilers for this one type airplane alone.

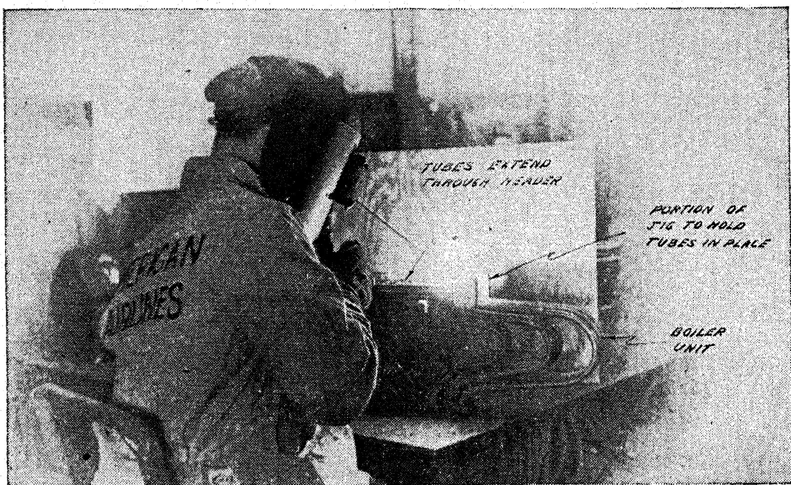

Fig. 7. Arc welding an airplane boiler unit.

As shown by the cost tables, American Airlines could construct the boiler for $168.16 using the old method of welding and get the same amount of service as with the factory made units. Considering four repairs at $20.00 each and the average life of 75 hours, the boilers were costing $248.16 for five periods of 75 hours each or $49.63 per period. At 2.87 failures per day this amounted to $142.44 per day or $51,990.60 per year providing the boilers were made in the company shops. At this figure, boilers for the industry would cost $336,205.88 using the former method of welding.

By constructing the boiler with the use of arc welding, the shop cost was decreased from $168.16 to $106.94 each. Service life was increased to a consistent operation of 450 hours at which time the boilers are destroyed. Figuring 215 scheduled hours per day, and a service life of 450 hours, American Airlines uses 174.4 boilers per year at a total cost of $18,650.34 per year for shop made arc welded boilers. At this figure, boilers could be furnished the industry for $118,805.92 per year.

*COST OF DST & DC-3 BOILERS

Former Welding Method

	Boiler Shell Fig. 6		Boiler Unit Fig. 3	
Labor: At $.75/hr. (Includes fabrication, welding, and testing).	8 hrs.	$ 6.00	46 hrs.	$34.50
Materials				
(a) Sheet Metal 7.88 lbs. at $.454/lb.		3.58		--------
(b) Tubing 34 ft. at $.56/ft.		--------		19.04
(c) Header Plates Material and Machining 2 at $6.05 ea.		--------		12.10
(d) Sumps Material and Stamping 2 at $1.05 ea.		--------		2.10
(e) Oxygen $.009 per cu. ft. 20 cu. ft.		.18	80 cu. ft.	.72
(f) Acetylene $.0275 per cu. ft. 18 cu. ft.		.49	72 cu. ft.	1.98
(g) Welding Rod ½ lb. at $.60/lb.		.15		.45
(h) Miscellaneous (Rivets, Fittings, etc.)		.39		.15
TOTALS		$10.79		$71.04
ASSEMBLY 3 HRS.				2.25
		Cost, Boiler Shell		10.79
		BOILER COMPLETE (Less Overhead)		$84.08

* The totals are actual costs taken from shop records. The cost breakdowns were made after having itemized the costs of several boilers.

*COST OF DST & DC-3 BOILER

Arc Welding Method

	Boiler Shell Fig. 6		Boiler Unit Fig. 3	
Labor: At $.75/hr. (Includes fabrication, welding, and testing).	7 hrs.	$5.25	10 hrs.	$ 7.50
Materials:				
(a) Sheet Metal 7.88 lbs. at $.454/lbs.		3.58		--------
(b) Tubing 34 ft. at $.56/ft.		-------		19.04
(c) Header Plates Material and Machining 2 at $6.05 ea.		-------		12.10
(d) Sumps Material and Stamping 2 at $1.05 ea.		-------		2.10
(e) Power .998 KW x 1 hr. x $.2005		.20	(same)	.20
(f) Electrodes ½ lb. at $1.70/lb.		.21		.64
(g) Miscellaneous (Rivets, fittings, etc.)		.25		.15
TOTALS		$9.49		$41.73
ASSEMBLY 3 HRS.				2.25
		Cost, Boiler Shell		9.49
		BOILER COMPLETE (Less Overhead)		$53.47

Cost, Former Method	$84.08
Cost, Arc Welding Method	53.47
Savings by Arc Welding	$30.61

* The totals are actual costs taken from shop records. The cost breakdowns were made after having itemized the costs of several boilers.

These figures show that American Airlines is saving $38,950.00 per year over the factory prices, and $33,340.00 per year over the former welding process shop prices on the heating system boilers, on this type airplane. Under the same conditions, the saving to the industry would be $253,674 per year over the factory prices and $217,400 per year over the former welding method shop prices. The comparisons with the factory prices are not true comparisons due to the fact that the factory prices include profit, but are included to show actually what American Airlines is saving, and what the industry could save by building their own boilers by the arc welding process.

The writers do not feel justified in stating that the savings shown above, and the improved service mentioned, was due wholly to the use of arc welding because no doubt some of the improvement was due to improvement of welding and fabrication technique, changing of angle that tubes enter the header plate, and other contributory aids. However, it is undisputable that arc welding was by far the major factor, and at least it is definite that the decrease from $168.16 to $106.94 in the shop costs was due entirely to the use of arc welding.

Just as a matter of comparison, the authors will assume that the service life of the boilers did not increase when constructed by the use of arc welding, but remained at 75 hours. As already mentioned, the boilers welded by the former method were costing $51,990.60 per year, and the ratio of the shop costs of the two methods of construction shows that the arc welded boiler only costs 63.6% of the former type. At this ratio, the yearly cost of the arc welded boilers would be $33,066.00 or a saving of $18,925.00 per year to this company alone, even assuming that the service life was not extended when arc welding was used.

Summary.—Heating of commercial and military airplanes by means of a hot air system is inherently unsafe, and the generally accepted method of heating is by means of a steam heating system. This type of heating has been very satisfactory excepting that boilers were failing with an unreasonably short period of service. This resulted in a detrimental passenger reaction, and in a great expense to the operator.

Much redesign and experimenting was done and some improvement was shown, but the boilers were still averaging only 75 hours service. American Airlines constructed the same boiler using arc welding and is obtaining a consistent 450 hour service life, and at a much lower cost. The results are a very favorable improvement in passenger comfort and a saving of approximately $38,950.00 per year over the factory cost, and approximately $33,340.00 per year (64.1%) over the former welding process shop cost to American Airlines. This would result in a saving of $217,400.00 to the industry for this one type airplane, providing the units were arc welded.

The potential possibilities of an arc welder are many, and we have investigations in progress now that if successful will show even greater savings than those already accomplished.

Chapter II—Arc Welding in Aircraft

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It has long been admitted that arc welding is basically a much cheaper method of fastening than the riveting process now almost universally used on all metal aircraft; and that arc welding is definitely applicable to tubing, offering structural advantages in many cases over the open sections required by conventional practice. But since such welding cannot be used satisfactorily on very thin stock, the aircraft industry has hitherto been unable to avail itself of this fundamental economy. Also no entirely satisfactory method has heretofore been established for attaching metal skin to a welded tube structure.

In this paper is advanced a type of construction and method of design which will permit arc welding and its inherent economy in a modern all-metal type of aircraft, together with other important advantages. The result is accomplished by concentrating the steel frame elements into relatively few members and employing the existing pressure forces to stiffen the skin, the latter being preferably attached by screws of the self-tapping, self-locking type. The general method is applicable not only to aircraft, but more broadly to any structural surface supporting normal pressure.

There are two general types of aircraft structure in current use: (1) the truss type with fairing and a fabric cover, and (2) the reinforced shell or stressed-skin type. The truss type is usually made of welded chrome-molybdenum steel tubing while the reinforced shell is fabricated by riveting stiffened aluminum alloy skin to frame elements of similar material.

Welding, where applicable, is admittedly the cheapest, simplest and best method of joining the frame elements. Unlike riveting, there need be no duplicated material in the joints; tube sections can be readily used where advantageous; and the end fixity coefficient is increased from about 1.5 to 2.0, with a corresponding gain in strength and stiffness. To compete with aluminum alloy, however, as to strength and weight in the highly stressed members, requires the use of high tensile steel, but this immediately introduces a number of problems hitherto generally unsolved except for fabric covered, and to a minor extent, spot welded, airplanes.

Briefly, these problems are:

(a) Proportioning and mounting the individual members for maximum structural efficiency while retaining the thickness necessary for arc welding.

(b) Employing materials and a process of assembly that will minimize the injurious effect of the welding heat.

(c) Stiffening the skin by other than direct structural means, to permit the enlarged panels implied in (a), without added weight penalty.

(d) Devising skin fastening means to permit its convenient attachment to tubing, and easy removal for inspection and repair (thus matching one of the few advantages of fabric).

It appears unnecessary to quote detail figures to show the generally recognized fact that alloy steel, such as chrome-molybdenum, can be heat-treated to strengths that are superior, weight for weight, to aluminum alloy, providing it can be used in a form to prevent local buckling of the structural sections by compressive or beam loads as implied in (a). The four principal methods of doing this are by:

1. Continuity of support.
2. Continuity of section curvature, or closely spaced bends (e. g., corrugations).
3. Use of closed sections, usually tubes combining item No. 2.
4. Maintaining a substantial thickness.

It can readily be shown that smooth skin of usual thickness is capable of carrying substantial compressive or beam stress only with practically continuous support. A corrugated surface-skin is now almost obsolete because of its air drag. Making the skin a compression member by its mere thickness is entirely impractical with any of the materials here considered. Hence only the frame elements will be considered affected by the above items, any skin-stiffening structure being considered part of the framing.

As the continuous support of a frame element will be mainly by the skin or other thin sheet, item No. 1 is clearly outside the province of arc welding, and if used must depend on other means, mainly concerned with the method of skin attachment. Items No. 2 and No. 3 are well served by arc welding. As to item No. 4, the problem is one of arranging the general design in such a way as to permit the thickest possible members that can be fully utilized. This is also desirable from the standpoint of resistance to corrosion, for any steel except stainless; and it is of basic importance if arc welding is to be satisfactorily used. In fact, the main drawback to gas welding has been the difficulty of doing a satisfactory job on thin sections. This is more particularly true of arc welding which is otherwise generally acknowledged to be cheaper than gas.

Another major objection to the welded steel frame has heretofore been the supposed necessity for a fabric cover. This has been due not only to the weight of incidental stiffeners thought necessary for skin support, but to the fact that in the case of tubing there has been no entirely satisfactory method of fastening metal skin to this type of frame. Here arc welding is apparently out of the question, and open sections are usually called for either by the prevailing riveted attachment or by spot-welding.

It is not so much the function of this paper to describe the economies of arc welded construction over riveted construction, which everyone knows, as it is to set forth a type of design, embodying arc welding, that is usable in aircraft.

In aircraft, as in anything else, the cheapest structure in the world is still good for exactly nothing if it cannot be used. How then are we to make use of the fundamental structural and economic advantages of arc welding, still keep our structure light enough for aircraft, and, at the same time, permit use of a metal skin? A type of construction is here advanced permitting heavier members but fewer of them, arc welded to-

gether, with suitable means of attaching a metal skin thereto; shown to be the cheapest from almost every point of view, applicable to all sizes and types, structurally sound; and susceptible of actual weight reduction in comparison to most present types. As will be seen, this type of construction is equally suitable for fuselages, wings and airship hulls.

The specific features here proposed are all tried and proven, but the combination has not as yet been used. The Navy's metal-clad airship, ZMC-2, now* completing its ninth year of successful service, embodies many of the physical principles involved.

A recent self-propelled rail car embodies a welded steel tubular frame with a stressed dural skin attached to it by means of hardened, self-tapping screws, here advocated for aircraft.

Since this rail car, a similar type of construction has been used in various automotive units with signal success, notably in light weight motor coaches for over two years. The operation of these busses, under conditions of vibration substantially worse than anything in aircraft, has shown consistently excellent results. Unlike ordinary wheeled passenger vehicles, however, the surface skin of aircraft is subjected to the action of substantial pressure forces which must be taken into account.

Pressure Forces.—Stressed-skin construction is in general so common that no detailed description of it will be necessary here; but the method of stiffening the surface to withstand the above mentioned pressure forces is vital to the present discussion. This surface stiffening is usually done in one or both of two ways. Either many closely-spaced separate, flanged stiffeners are riveted inside the skin (bottom of Fig. 1),

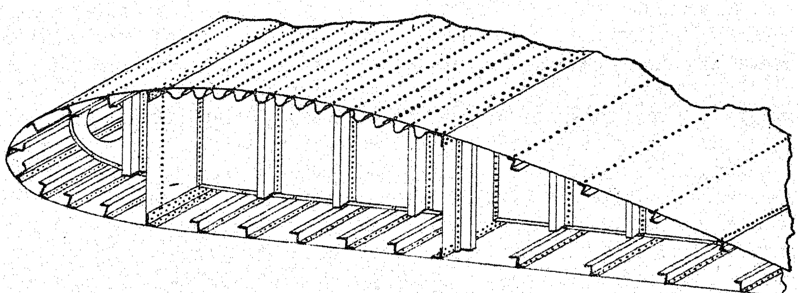

Fig. 1. Airplane wing section showing present all-metal airplane construction of riveted 24 ST Alclad.

or, as is becoming more common, the skin at least in part is built up of two layers, the outer layer being of smooth sheet running from .010 to .030 in thickness, while the inner layer is two to three times as thick and is corrugated (top of Fig. 1). This method has the stiffness characteristics of the old Ford Tri-motor type construction in a direction that will do the most good, without the attendant increased surface friction. However, from the economic point of view, both current methods are sadly inefficient because of the large number of rivets required to make satisfactory fastenings between the outside skin and the inside stiffeners.

*At time paper was written.

The method herewith proposed for stiffening smooth aircraft skin has been used with outstanding success on the above mentioned airship ZMC-2. By this method, panels as large as seven feet by sixteen feet of .010″ 17ST Alclad were satisfactorily stiffened with no extra weight or added members of any kind. Fantastic as this may sound, the facts borne out by the ZMC-2 are indisputable.

The result is accomplished by maintaining and utilizing a pressure difference of small magnitude acting normal to the skin and always in the same direction. With this pressure difference, calculations and tests both show that there will be no tendency for the skin to flutter, and that the skin will be able to carry the designed shear stress without serious wrinkling. Theoretically and practically, in the case of the ZMC-2, the forward speed of the ship was found sufficient to maintain the required pressure difference at all times. The airplane, with its higher speed, will be still more definitely susceptible to this type of pressure control. In the event of local damage to the skin, the general redundancy of structure serves to carry stresses around the injured spot. This has been verified by practical experience as well as by mathematical analysis and laboratory tests.

The external pressure distribution of the air around a wing in flight has been an object of study for some time, but the internal pressure has been left entirely to chance. As is well known, the maximum external pressure is confined to a narrow strip along the leading edge. This is easily reinforced by structural means. The outside pressure drops off so fast from this point that it is quite unnecessary to have as much pressure inside. Also the pressure is so much lower on top than on the bottom, that in some cases it is sufficient to have a pressure inside such that the pressure difference on the surfaces acts outward on the top and inward on the bottom. In either case, controlling air vents are put at the proper points to insure the desired results. Scoops or leading edge vents (Fig. 3) of course give the maximum pressure. The wing volume being small and the screwed seams relatively tight, only small intake openings are needed if properly located, the actual size being mainly governed by the diving speed. Both inside and outside pressures are then automatically generated in proper proportion by the effect of the air-speed itself and the angle of attack of the wing, ground stresses being independently allowed for.

As can readily be seen, this very substantially simplifies the construction, besides concentrating the frame elements as required for arc welding. In the case of a fuselage, since the section is usually nearly symmetrical, the pressure would have to be great enough for the difference always to be acting outward. If the cabin is supercharged for high-altitude flight, the problem is already taken care of. If not, it is solved in the same way as for the wing. (Figs. 2 & 3).

Frame Elements.—Considering the type of structural sections to be used, it must be admitted that if sufficiently thick members can be justified, particularly those which are well supported against buckling, tubing becomes less important, and other considerations may prevail in the design of specific parts. Skin attachment by screws, recommended in either case, is particularly desirable in the case of tubular supports, it being important however to use properly a type and size of screw suited to the

purpose. Such screws have been shown to be particularly reliable when used in steel.

For purposes of illustration, the wing is chosen because it is considered to be the most important and critical part of an airplane. Two convenient methods, embodying the above principles, are shown for obtaining an arc welded structure of high tensile steel. The first is the most straightforward, consisting merely of using initially heat-treated or high tensile stainless stock in the fabrication, preferably the latter.

Here the wing beam is made up of two corrugated stainless steel

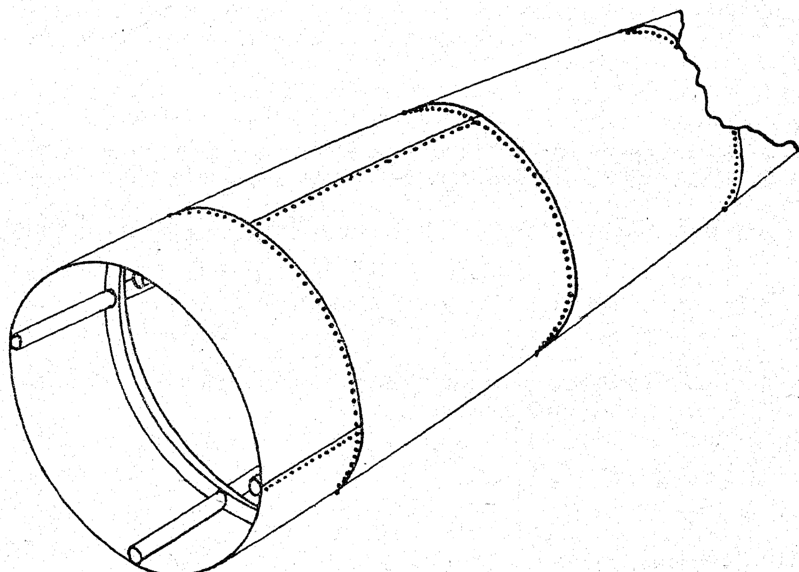

Fig. 2. Proposed arc welded fuselage construction. Skin screwed to arc welded tubular transverse frames—air intake forward.

flanges with lattice tubes of similar material, arc welded in place (Fig. 3). The flanges are tapered in width toward the tip. It should be noted that the corrugated flange is here used purely as a beam flange and does not support the skin. Hence it can be made relatively narrow and of substantial thickness. In this type of construction, the rib members are preferably screwed to the beam flanges.

The second method is to use un-heat-treated stock to form sub-assemblies of such a size as to admit them to furnaces and quenching tanks readily available. These sub-assemblies are then heat-treated after fabrication, and assembled by telescoping them together. They are secured in place by a series of "slot" welds (Fig. 4), designed to distribute the welding heat in axial lines and prevent loss of strength in the section as a whole. In this type of construction, the rib members can be arc welded in place, by similarly restricting the lines of weld, with little loss of strength in the beam flange.

Arc welding is ideally suited to both of these constructions since the heat produced is highly localized. In either case, there is no need for diagonal bracing in the plane of the skin since the skin is an integral part

of the structure and is designed to take the shear loads, developed as tension. As to cost, there is little choice between the two. However, it must be remembered that the economical use of corrugated or other open members is restricted to straight elements detached from the skin, tubes being otherwise much easier and cheaper to handle.

The skin may be fastened either to the spars or to the ribs with almost equal structural efficiency, but from aerodynamic and other considerations, it is deemed more satisfactory to use the rib fastening which can be set on a spacing up to 8 times that of present stiffeners. In the case of a fuselage, it is usually more expedient to run the skin panels circumferentially with countersunk screw attachments to the transverse frames. (Fig. 2).

In a wing designed by the author, the main beam is built up of heat-treated sections telescoped together as described above. The ribs are placed perpendicular to the leading edge instead of parallel to the chord so that the skin can be fitted on in straight, unbroken strips from under the trailing edge around the leading edge to the top of the trailing edge, without patterning.

Cost Analyses.—As an aircraft of this description has not yet been built, its cost must be estimated from knowledge and judgment based on the cost of materials, and experience with the various operations involved. The essential object will be to get a cost comparison between an arc welded chrome-molybdenum steel tube frame with screwed-on skin, and conventional riveted dural construction.

On the above mentioned rail car, the following figures applied as taken from observation of average workers on basic operations:

	Time in minutes	Labor costs	Mat'l costs	Total
Plain "T" weld 1½″ O. D. tubes ...	10	$1.00	$.075	$.175
Continuous plate weld per inch	1	.010	.015	.025
Drilling and screwing per screw	1.5	.015	.005	.020

Applying this data to the construction of a pair of 20′ tubular wing spars and the skin attachments thereto, we find the cost analysis to be thus:

Cutting and fitting	$ 5.00
16 joints averaging 25¢ each (gussetted)	4.00
120 lattices @ 15¢ each	18.00
Misc. details	6.00
600 skin screws, inserted, @ 2¢ each	12.00
Total of above operations	$ 45.00
115# of heat-treated chrome-molybdenum tubing @ 50¢/# ...	57.50
Total of labor and material	$102.50

However, this does not give us the true picture because on this car, the screws were driven by hand, and the welding was done with gas. The reduction in direct welding costs is partially compensated for by a slight increase in the cost of tube fitting which must be done more carefully for arc welding than for gas if standard practice is to be accepted. As

for power screwdriving, recent experience in two different plants indicates that it is at least three times as efficient as hand driving, reducing the labor cost of screwing from \$.015 to \$.005 per screw. Thus correcting the above figures, we have as a liberal estimate:

Cutting and fitting	\$ 7.00
16 joints @ 10¢ each	1.60
120 lattices @ 10¢ each	12.00
Misc. details	6.00
600 skin screws inserted @ 1¢ each	6.00
Total of above operations	**\$32.60**
115# of heat-treated chrome-molybdenum tubing @ 50¢/#	57.50
Total labor and material	\$90.10

Now let us investigate a comparable structure of riveted aluminum alloy (24ST). These figures are also based on time studies:

Flanges (layout, notching & reinforcing)	\$ 54.00
Lattices (layout and assembly)	27.00
Misc. details	14.00
Spar assembly	48.00
600 skin rivets inserted @ 3¢ each**	18.00
Total of above operations	\$161.00
125# of 24ST sheet and rolled sections @ 50¢/#	62.50
Total labor and material	\$223.50

This is 150% more than the arc welded steel construction to say nothing of its being ten pounds heavier, the strength being the same.

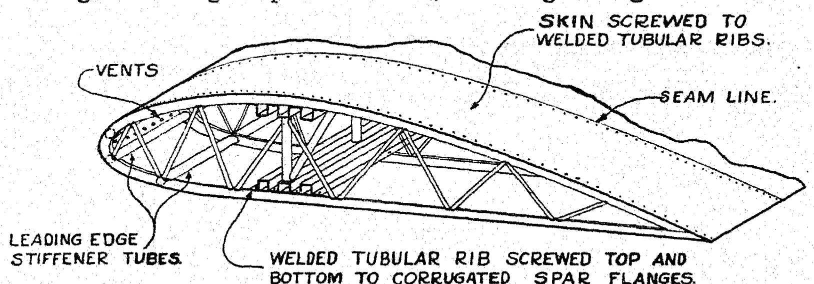

Fig. 3. Arc welded stainless steel wing—all frame joints gussetted.

It should be noted that the above comparison is between wing beams of closely similar type except for the material and method of assembly. If the proposed welded steel construction (Figs. 3 and 4) with concentrated frame elements is compared to the type of construction at present actually used for all-metal aircraft, the latter appears still less favorable because of the supplementary riveting required for the attachment of skin stiffeners or alternative corrugated layer (Fig. 1). In other words,

**The inserted cost of skin rivets on present all-metal airplanes averages from 3¢ to nearly 10¢ each.

the improved construction is not only cheaper per joint, but there are far fewer joints in the structure as a whole.*

It is extremely doubtful if the above costs include enough allowance for delays caused by mistakes in cutting and fitting the many different gussets, drilling out and replacing bad rivets, etc. Bending the 24ST sections is a much more serious problem than bending steel tubes; and a modern airplane must necessarily include a large proportion of curved members. The mounting of the various small fittings may take anywhere from twice to four times as long when riveted as compared to welding (or screwing to a welded steel frame).

When making up 50 to 100 complete units at once, the direct labor on the welded construction would remain substantially the same, while the labor per unit on the riveted construction is lowered considerably. In the industry, opinion differs as to the amount of this reduction, but even the most drastic estimate reduces it by only one-half, which leaves the riveted construction still costing almost 60% more than the welded steel tube type, neglecting entirely any reduction in the latter.

The comparative drafting time required to design an airplane for alternative types of construction must necessarily be something of a guess, but informed opinion again leads to the belief that the riveted type would be at least 50% more than for a comparable arc welded steel job. This in itself would not be so serious if it could be amortized over a large number of identical units, but any change or new fitting desired will always involve work in the drafting room as well as in the shop.

Using estimates based on the above considerations, the following percentage savings from present costs, for the various sizes and types of completed units, seem well on the conservative side:

For a large rigid airship 20%
For any present all-metal air transport............30%
For an airplane such as the Waco Cabin or
Stinson Reliant 0%
For a light plane such as the Cub or Aeronca
....10% increased cost

In terms of dollars and cents, these figures take on the following aspect:

Since the late airship Hindenburg cost in the neighborhood of $4,000,000, the same size could be built in this improved way at a saving of $800,000 approximately. An airplane the same size as the Douglas DC-4 could be built for $350,000 as compared with the reported present production cost of $500,000; a net saving of $150,000. An airplane of size comparable to the Waco or Stinson would cost substantially the same as the present ship, while a small light plane would cost somewhat in excess of $100 over current costs, due to the restricted applicability of arc welding for the light framing involved. However, in these last two examples, one must not lose sight of the fact that although there is no present cost saving, the highly inflammable, easily damaged, fabric covered structures will have been replaced by stronger and comparatively

*The total number of rivets (reported to be 1,300,000 in the new Douglas DC-4) would be replaced by not over one fourth as many screws.

permanent all-metal structures of substantially the same weight, a result which, if attained by prevailing methods, would cost 50% to 70% more than the present ship. Similar improvement can be made in the present fabric covered airship at an actual saving in cost for any units beyond the first.

These cost estimates are for the entire aircraft, although the actual saving considered is for the main structure. If arc welding can similarly be utilized in important operations on the powerplant and other accessories, the total saving will of course be still greater.

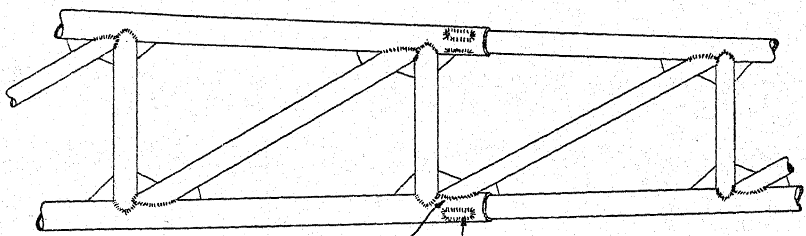

Fig. 4. Diagrammatic view of wing spar, showing method of using heat-treated subassemblies.

Other Advantages.—Low first cost is not the only attractive thing about this type of construction, even in comparison with present all-metal airplanes. Other points to consider are:

1) Incidental improvement of structural arrangement can be effected through not having to provide internal access to rivets.

2) The general segregation of structure allows plenty of room for wheel wells, fuel tanks, and miscellaneous commercial or military load.

3) Concentrated loads from landing gear, engine nacelles, etc., are readily handled; and the substantial character of individual members makes them generally able to take "punishment."

4) Subject to effective corrosion prevention, steel is known to have a higher fatigue limit than the "light" alloys.

5) Inspection and repair are greatly facilitated by the reduced number of frame elements, and the screwed-on skin.

6) An appreciable saving in weight is possible and will probably be realized with further development.

7) Great rapidity and widespread facilities of production, using generally familiar materials and equipment will be a tremendous advantage in case of war.

Of the few possible disadvantages, assuming adequate material thickness here provided for, the matter of shop inspection should be mentioned. The difficulty as to inspection of arc welds in aircraft is not thought to be more than can be worked out by establishing suitably high standards, checked by a reasonable number of tests, and

rigidly enforced. The need for such standards must be recognized, however.

Shear wrinkles, although definitely avoidable under flight conditions, must be accepted to a certain extent on the ground. This can be restricted to almost any desired magnitude, however, by a simple means of prestressing the skin.

Possibilities for the Future.—In the light of research and development now in progress in new and better materials and equipment, it seems only reasonable to expect that cost can be reduced still further in the future, even to the extent that relatively small, fabric covered ships can be redesigned in metal at a substantial cost saving by making use of this improved construction. Most noteworthy of present developments is a new nickel-molybdenum steel that has better welding characteristics than the chrome-molybdenum alloy, together with more favorable physical properties. Another asset of this new steel is that all of its constituents are obtainable in this country and Canada.

Riveting, over the course of several generations, has been very highly developed. In fact, one is tempted to wonder whether its refinement has not reached a limit. Arc welding, on the other hand, is still in its infancy, and no limit to its possible attainments is yet in sight.

On the basis of arc welding equipment and technique at present available, the smaller aircraft will require the large proportion of non-arcwelded joints; but the principles of design and construction here shown will in any case permit a maximum utilization of the arc welding process, and other advantages inherent in the small number of parts. Although this paper is concerned with designing the product to suit arc welding conditions, rather than with the production equipment, it is worth noting that further refinement of such equipment and methods of use will be most valuable in the direction of permitting general assemblies to be formed from thinner stock. Using the structural features here proposed, ability to reliably arc weld steel down to about .016″ thickness (28 ga.) with full strength, should take care of the major part of any airplane, except skin attachment, regardless of size.

In spite of the high first cost of present all-metal air transports, they have been found far more durable and more economical in operation than fabric covered ships. For private operation, however, the first cost has been an almost complete barrier to the use of all-metal construction. What is needed is a method by which all-metal private aircraft can be produced, in relatively small quantities at first, but at a price to compete directly with fabric. Even though it may involve no initial cost saving, this should be an important factor in promoting the increased sale and production on which production cost itself so largely depends.

Hence, the approximate $2,000,000 per year that can be saved in the air transport industry, as at present constituted, may be of small importance compared to the increase of business that may be stimulated, especially in a field that has hitherto been relatively neg-

lected but is potentially the biggest of all, the private market. Arc welding, with suitable structural design, is a key to this situation.

The proposed construction, increasingly feasible for larger craft, will here provide a welcome simplicity in comparison to the ever-increasing structural complication of large aircraft to date.

Conclusion.—Subject to design criteria developed in connection with this paper, (see summary of Appendix material) the arc welded, concentrated steel construction, with screwed-on skin under the proper normal pressure, has qualities that should make it more economical and generally more satisfactory than prevailing forms of aircraft in sizes larger than the very smallest airplanes; and it is expected that future developments will render even the latter class of airplanes susceptible to cheaper as well as better construction by this method. The author counsels against undue haste, however.

In this, as in any new design, progressive refinements from practical experience, together with inherent economies and other advantages, can be fully realized only through slow, orderly development.

APPENDIX TO PAPER (SUMMARIZED)

Effects of Local Pressure and Strain on Large Stressed-Skin Wing Panels.—This part of the paper deals with the mathematical correlation of practical stress conditions specifically applicable to the most critical part of an airplane, namely, the wing. The basic analysis, however, is so fundamental as to underlie practically all structural use of large skin panels subjected to normal pressures. Hence it is broadly applicable not only to other aircraft parts, but to tanks, containers, boat hulls, etc., where it will be of similar service to arc welders by facilitating the design of a structure of maximum efficiency and minimum cost.

Important progress has been made in recent years toward the understanding of thin-skin behavior under known stresses. In applying the results to actual wing design, however, the true stress has been largely unknown, due to neglect of the normal pressure forces and local strain, except in so far as they affect the general load distribution and the values of shear, bending moment and torque on the wing as a whole.

The neglect of the above mentioned items can be shown to be of small consequence for the very small unsupported skin widths, usually not more than 5″, at present in common use. But the same items are of vital importance for any great increase in skin width or decrease in thickness.

An argument originally advanced for the reinforced type of skin is that it would help carry direct beam loads; but it is now generally recognized that this help is small, being limited to an "effective width" of not over 30 times its thickness. Thus even with skin as thick as .033″ it can be utilized only to the extent of ½″ on each side of a rivet line. Hence the general tendency now is to decrease the skin thickness in favor of putting the material where it will do more good, at the same time retaining for the skin the function of carrying tensile

and shear stresses. This analysis carries the same process to a logical conclusion, the specific objects being: (a) to develop means of approximating the true stress in the skin, as the only sound basis for experimental coordination of stresses, not only in the skin itself, but in all members associated with it; and (b) to proportion the controllable elements of the design in such a way as to keep the skin smooth under the required shear stress with the least possible weight and number of structural parts.

The mathematical treatment follows "standard practice" of Timoshenko, Prescott and others in respect to the general physical basis of the problem. The integrated equations are expressed in a form for improved accuracy and convenience, by the use of co-efficients that can be assumed constant in approximate computations for which the working equations are relatively simple. Any further order of accuracy desired can then be had resubstituting the correct co-efficients. The practical engineering formulas cover deflection, stress, and buckling for any given combination of material properties, panel width, curvature, pressure, strain in the supporting structure, and superimposed shear load. From the standpoint of practical wing design, the results affect the following items:

1. Number of spars.
2. Rib spacing.
3. Choice of skin material.
4. Skin thickness and stiffening.
5. Skin deflection and buckling.
6. Effects of varying tightness of skin.
7. Temperature effects.
8. Level of internal pressure.
9. Structural implications of airfoil contour.
10. Torque stiffness as related to pressure and surface strain.

Although these items are worth considering for any airplane, they are particularly necessary in the design of structures with concentrated frame elements, suitable for the use of arc welding.

Chapter III—Arc Welding for Economy in Construction of Beaching Gears for Large Planes

By JAMES W. FITCH and JOHN CZARNIECKI, JR.,
Mechanical engineers, Kenworth Motor Truck Corp., Seattle, Wash.

Flying high over the blue waters of the Pacific, the new Boeing Clipper seeks her port, loaded with mail and cargo from the seven seas. She carries a passenger list of 72 people from all walks of life.

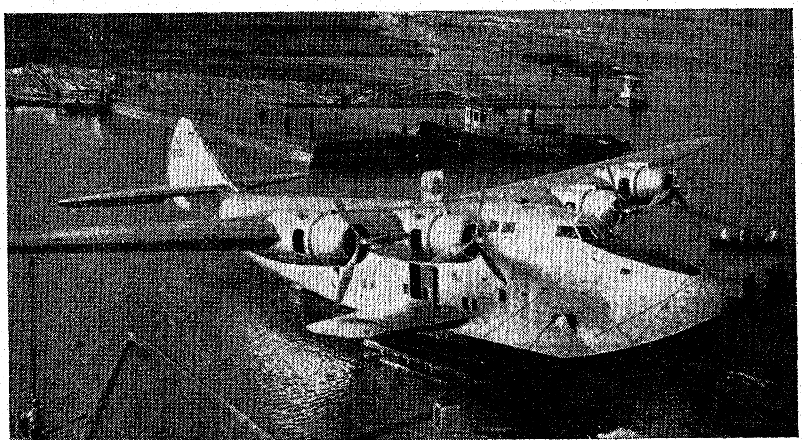

Fig. 1. Launching 41-ton Boeing Clipper by use of arc welded beaching gear.

This huge multimotored 41-ton sky giant lands and discharges her burden, but does not remain long, for soon she will be loaded and fly again to some far corner of the earth.

The precious time in port must be utilized to full advantage. Each man must be trained for his job, each piece of equipment must be of the best. The ship must be taken from the waters and into her hangar where she is dismantled for routine inspection and any doubtful parts repaired or replaced—herein lies the safety in air travel for eternal vigilance in maintenance paves the way for safe transportation.

Extreme precaution must be used in handling these luxurious air-liners. They are launched by means of a specially constructed beaching gear. The gear is floated out on the water and submerged beneath the ship and is then towed with the airplane thereon by means of two tractors up the ramp and into the hangar. This move must be made with minimum deflection on the ship for fear of buckling the delicate duraluminum plates comprising the hull thereby causing rivets to tear loose from their plates. The huge airship which measures 154 feet in wing spread and 109 feet in overall length must be stable on the gear and therefore must be fastened securely to prevent any rocking or tipping which would cause excessive deflections.

This paper presents the most modern development of beaching gears as used to launch, (see Fig. 1), and beach the world's largest aircraft which will soon be put into service on Atlantic and Pacific Ocean routes.

The possibilities of arc welded construction were not fully realized by the designers until approximately five months of research was completed. This research established, beyond doubt, the practicability and economy of welded construction in all its phases. The design of the beaching gears was started with the conventional riveted construction in mind, but was latter abandoned because of the advantages offered by arc welded construction.

Fig. 2 shows the structure upon which this paper has been written. It is known as Model 314 beaching gear and was designed for the Boeing Airplane Company by the writers. Twelve of these units are being constructed. Ten have already been delivered to various points on the Atlantic and Pacific Oceans. The remaining two are still** in the process of manufacture.

The beaching gear was designed to convey a load of over 87,500 pounds with a maximum deflection of $\frac{3}{16}$ of an inch. Actually it did not deflect this much for torsional rigidity tests proved that the maximum deflection was $\frac{5}{32}$ of an inch with a load of 87,500 pounds. This is equivalent to placing a weight of 20,000 pounds at the end of an eight-foot beam with a deflection of $\frac{5}{32}$ of an inch and transmitting the load through two joints to a rigid member.

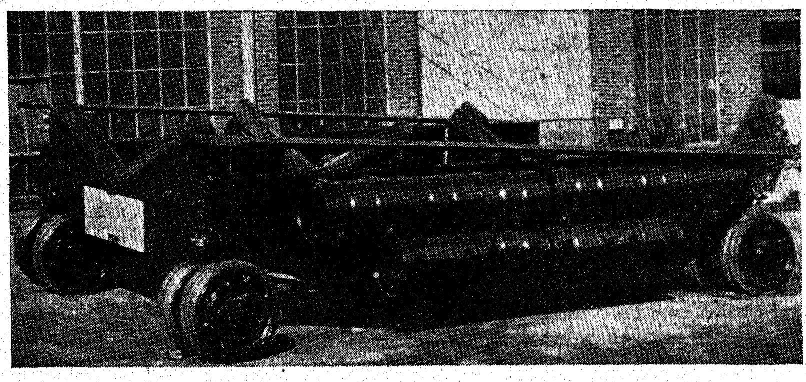

Fig. 2. Beaching gear for large aircraft fabricated by arc welding at 31.7% cost savings.

The main structure of the beaching gear is of all welded construction. Alloy steel castings were used where necessary and bolted on for servicing and transportation purposes. The corner castings and the trucks at each corner of the beaching gear weigh over 2,000 pounds and were made removable for the reasons just stated. A special alloy steel was used in the main and toggle axles to insure a high factor of safety.

The structure rides on eight solid tires while the Clipper rests

**At time paper was written.

on specially designed rubber pads. The gear is equipped with ratchet brakes on the four front wheels which were designed to stop the beaching gear and the Clipper in case of break-away while going up or down the ramp.

Each spindle is capable of being rotated plus or minus 360 degrees and may toggle plus or minus ten degrees making it possible to maneuver the beaching gear to any desired location. The beaching gear is 24 feet long, 18 feet wide and seven and one half feet high. It weighs approximately 15 tons, and is finished with a special anti-corrosive bakelite paint.

Fig. 3 shows a view looking at the intersection of a side-frame and cross-member with one of the X-frame members. The entire joint is of all-welded construction and shows the fine work done by the welders. The company took very much pride in the work turned out by the welders and looked far and wide for the best men obtainable. Note that these welds are not successive passes but a single woven bead.

The following is a partial list of some of the important items used on each unit:

1,200 feet of welding.
190 pounds of electrode.
512 man-hours of welding.
Over seven tons of mild steel.
1,900 pounds of rubber used in tires, pads, and rollers.

Some of the conditions in which the beaching gears are to operate offered a difficult design problem. The gears are to be used in practically every zone on earth and will be subjected to all types of weather conditions from the frigid climate of Alaska to the torrid heat of the South Seas. The severe corrosive effects of sea water, lubrication problems involving heavy loads, immersion in salt water and electrolysis between various metals had to be overcome.

The welded construction of the gear aided in solving these problems by presenting clean surfaces from which to work. No crevices between plates or members are presented as, for example, in riveted lap-joints. Fine surfaces were insured to guard against corrosion as well as improving the appearance.

As the unit becomes older and has become subject to much twisting and bending caused by the heavy loads that it must carry, a riveted construction would develop slippage between the rivets and plates, thus necessitating repair work to keep it watertight. In welded construction, the entire structure is like one solid mass and once made watertight it will remain that way.

The riveted construction being much heavier and bulkier than the welded cannot be handled in the water as easily. The welded gear can also be handled more quickly and easier on land due to its lighter weight. This saves beaching time which is an important item when planes have to be inspected and rushed back on their schedules.

In case of any repair to the welded unit it would require but one man, a welder, to put it back into service, while if a riveted structure failed it would require a riveting crew to make the necessary repairs. Thus, the welded job is far cheaper in maintenance than the riveted.

Arc welded construction made possible the extreme rigidity of the structure. Welding makes the members integral with each other by actually becoming part of the whole. In the welded structure, the beam members conformed to the rigid support formula for deflection.

Beam fixed at ends: Concentrated load located at center of beam.

$$D = \frac{WL3}{192\ EI}$$

With any other type joint the deflection formula generally would follow thus:

Beam supported at ends: Concentrated load located at center of beam.

$$D = \frac{WL3}{48\ EI}$$

In the above formulas "D" equals deflection, "W" equals load, "L" equals length of span, "E" equals modulus of elasticity of steel, "I" equals moment of inertia about the neutral axis of the beam.

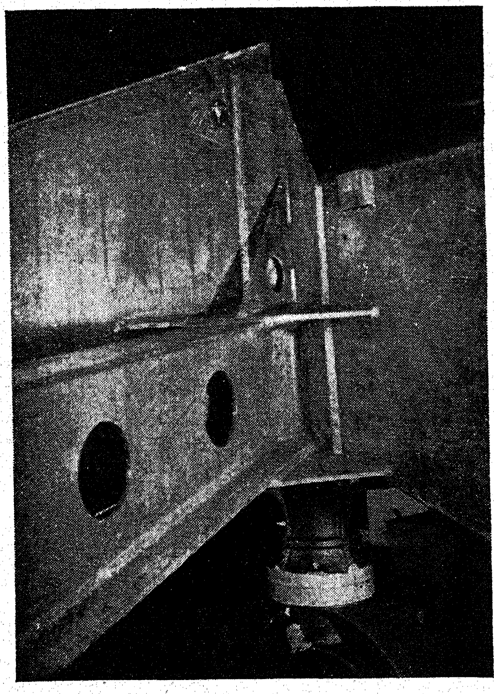

Fig. 3. Arc welded joint at intersection of side frame and cross member with X-frame member.

By using welded joints we realize the advantages of the rigid joint, hence, minimizing the deflection to one-fourth that of the free joint.

In the riveted construction, a certain amount of play exists between the rivet and the hole after loads have been applied, therefore, rigidity must be sacrificed because of the flexibility in the joint.

In this project, the flexibility of joints would have resulted in leaks on

all the riveted buoyancy tank members. These tanks must be watertight at all times and welding provides a happy solution to this problem.

The beaching gear was fabricated to provide buoyancy in each member as well as for the member to be structurally suitable. A box-section was finally selected as this type member offered the best rigidity with suitable buoyancy characteristics.

The unit was designed to float in salt water with an inherent buoyancy of 2,000 pounds. The additional buoyancy was provided by means of buoyancy tanks on the two long sides of the gear. Welding these members answered the purpose satisfactorily, for it was possible to save considerable weight, as well as eliminate flanges and rivets inside of each member which utilized valuable buoyancy space. This effected a saving of approximately 26 cubic feet of volume which is equivalent to 1,664 pounds of displaced weight.

Following are details of the work for both the riveted and welded constructions.

Riveted Construction.—The shearing and bending of fabricated parts was called out on bids as the company did not have the proper equipment. Two men are required to lay out the holes for the 3,026 rivets. Both men handle the large parts such as side frames and crossmembers. An average of approximately 25 holes can be layed out per hour considering the time spent in handling and positioning the work.

From our investigations, we found that more jigs and templates were required for riveted construction than for welded. The reason for this was that all holes had to be located, flanges had to be considered, and more individual parts had to be jigged-up. Some of the templates, such as the ones required for the crossmembers and side frames, were made from ¾-inch plywood, while all the jigs had to be made from light structural steel and light-gauge sheet metal. It was estimated that 160 man-hours would be required to complete all the jigs and templates. The material amounted to $210.

Approximately 650 pounds of rivets were required per job. This includes ten per cent spoilage and loss.

Approximately 1,000 feet of seam would have to be made watertight while about ten per cent of the rivets would have to be caulked. All sections would have to be tested under eight pounds per square inch of water pressure. Under these conditions, no water leaks are permissible.

The total weight of structural steel required for riveting amounted to 17,610 pounds. This weight was made up of the following items:

Rear crossmember	1,908 pounds
Center crossmember	1,974 pounds
Front crossmember	1,500 pounds
Front "X" frame	2,220 pounds
Rear "X" frame	2,350 pounds
Rear tube supports	150 pounds
Left side frame	3,209 pounds
Right side frame	3,209 pounds
Gussets to reinforce "X" frame with side frame	1,090 pounds
	17,610 pounds

Welded Construction.—The shearing and bending was done by a contracting firm that specializes in this type of work.

It required 16 days for a crew of two certified welders, one ship fitter, and one helper, to do the 1,200 feet of welding that was required per job. The cost per foot of weld was $0.423. In order to insure the best workmanship, our men were instructed to sacrifice speed for the best that they could produce. Many difficult welding positions were encountered, such as welding in tight overhead corners. Approximately 40% of the welding was done by the men while they were in members ten inches deep and welding on their stomachs and working their way along for a distance of 24 feet. They were so cramped for room that they could move only their heads sideways. Electric fans were installed to blow out the fumes ahead of the welder as he progressed. Special electrode holders were used which could be laid down without sparking.

The labor expended for templates and jigs amounted to only 30 man-hours; the material for templates and jigs—$28.00. The templates were made from plywood and the jigs were made from light structural steel and sheet metal.

Two special rod clamps were required to hold the side frames and cross members together in preparation for welding. These were made up at a cost of $10.00.

Each job required 190 pounds of shielded arc electrode. Three sizes were used, 1/8", 3/16", and 1/4" at $ .13 per pound. The rod cost was $24.70 per job.

Although all the welding was chipped and cleaned with a steel brush, a safety precaution was used to insure the paint from coming in contact with microscopic particles of alkali left from the flux of the rod. A dilute

Fig. 4. Welds at intersection of X-frame members. The members are 60-pound I-beams with 1/2 inch top and bottom gussets.

solution of copper sulphate was used to neutralize all the welding before painting.

The total weight of structural steel per unit for arc welded construction amounted to 14,258 pounds. This weight was made up of the following items:

Rear crossmember	1,347 pounds
Center crossmember	1,370 pounds
Front crossmember	1,184 pounds
Front "X" member	1,296 pounds
Rear "X" member	1,505 pounds
Rear tube supports	134 pounds
Left side frame	3,206 pounds
Right side frame	3,206 pounds
Gussets	1,010 pounds
	14,258 Grand total

Due to welded construction, each job was lightened 3,352 pounds.

The saving in weight was a very important item because it meant that fewer buoyancy tanks had to be provided, smaller wheels and tires and smaller wheel bearings could be used. The lighter welded construction required ten less buoyancy tanks. These tanks are ordinary 55-gallon oil drums with special filling and drainage equipment for trimming the beaching gear for proper flotation. The set of wheel bearings for each job was less than for the heavier riveted construction. Anyone can readily understand that going from a heavier to a lighter construction affects savings.

The Kenworth Motor Truck Corporation has found that by welding they can fabricate and construct beaching gears for the giant "Clippers" at 68.3% of the cost required for riveting, thereby saving the buyer 31.7% on the purchase price.

Only through welding were these twelve units possible.

Our research in both the riveted and welded fields has proved that welding is much more economical than riveting and also has started a new era of welded-fabricated-design at our plant which previous to our investigations would not have been possible.

Welding science is contributing to a new era in transportation. It makes possible the things thought impossible in yester-year. In the near future, multi-motored flying boats will traverse the globe in peace time and will protect our homeland in troubled times. Ocean travel will be faster and more comfortable than ever before. Nations will be brought closer together, and mankind will reap the benefits from the new ideas, manners and customs of foreign lands.

Chapter IV—Arc Welded Aeroplane Landing Gear Fork and Tests of Aircraft Welds

By C. R. De Laubenfels,
Research engineer, Lockheed Aircraft Corp., Burbank, Calif.

This paper presents the adaptation of an existing structure for arc welding. The structure, as previously made, was welded together by another method, but after one landing gear, (See Fig. 1), failed in service in the weld, and another, in the subsequent proof test, failed in the same place, the design was changed to arc welding.

It was brought to the writer's attention that the landing gear had failed. He tested a similar part taken from the production line.

Static Test of Landing Gear Fork.—The fork was tested in the jig shown in Fig. 2.

The table gives the loads and deflections. On further loading the jig failed. Examination of the fork showed no apparent set.

Load in 1000 lbs.	Defl. in inches.	Load in 1000 lbs.	Defl. in inches.
0	0	24	3/8
5	1/16	25	3/8 +
10	1/8	26	7/16 −
15	3/16	27	7/16
17	1/4	28	7/16 +
19	9/32	29	15/32
20	5/16 −	30	1/2
22	5/16 +	31	17/32

After the jig was repaired the test was continued but deflections were not read. The maximum load carried was 46,000# which was being supported by the fork in Fig. 2. However, it was considered that failure had occurred because the crack shown in Fig. 3 had opened and the tube had buckled.

The crack had occurred in the weld at the edge of the gusset. The tube was sawed off and the crack spread, (See Fig. 4), to permit examination, which showed very poor welding at the point of failure.

Following the test of the landing gear fork, the writer suggested the change in welding method, and after considerable argument, was able to convince the factory that arc welding would be an improvement. At that time there was considerable opinion that arc welding was not as good as the method in use, and there was some strong resistance to the change. This opinion has changed since, and practically all similar structures are now arc welded in the Lockheed plant.

In the Lockheed factory, methods of fabrication have been considered

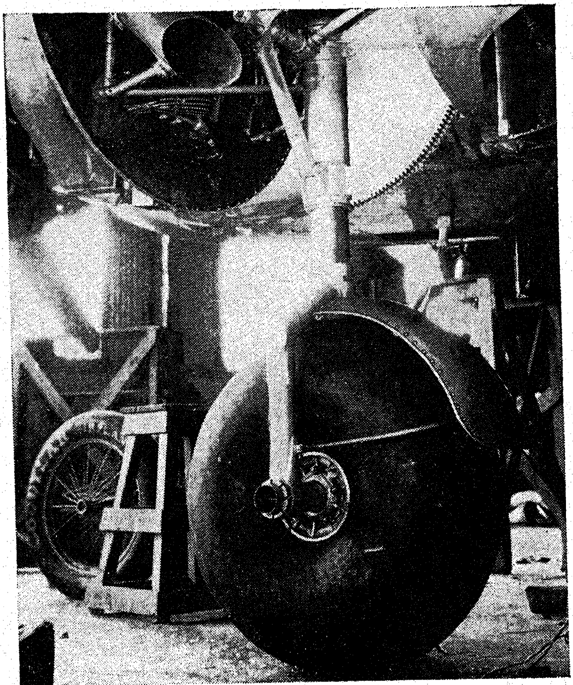

Fig. 1. Airplane landing gear fork.

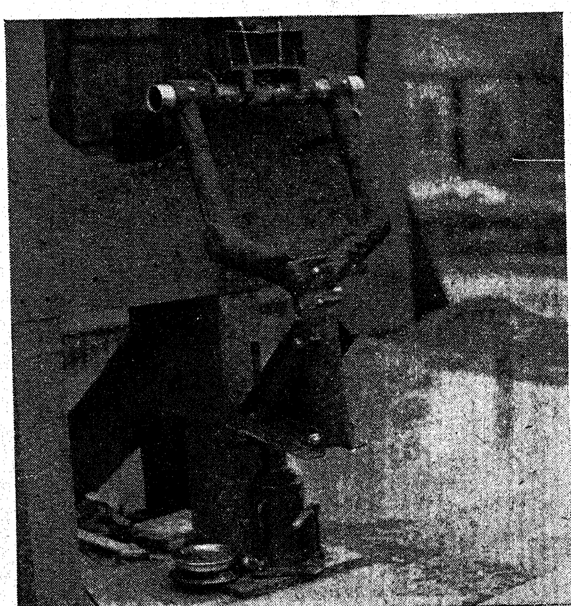

Fig. 2. Landing gear fork in jig for testing.

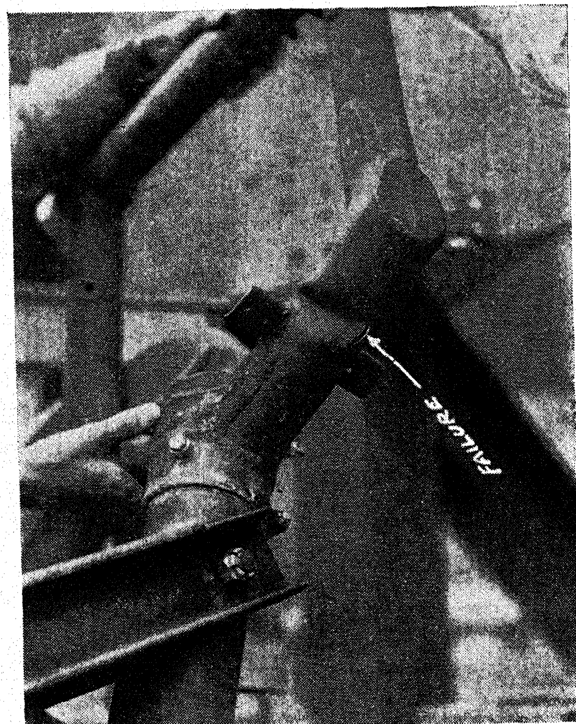

Fig. 3. Landing gear fork after failure.

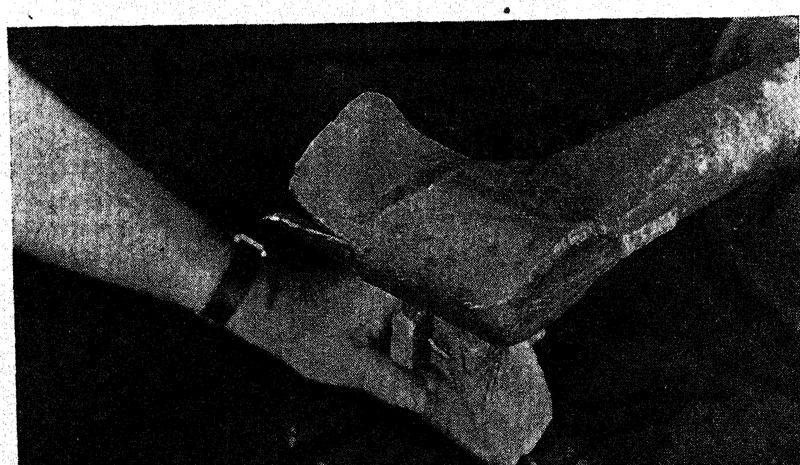

Fig. 4. Tube of landing gear fork cut off and split open for examination.

a function of the factory rather than the engineering department, and welding specifications were not a part of the drawing. The factory procedure now is to arc weld all structures of a nature similar to the fork shown, and especially those where the warping due to other welding would cause difficulties.

LOCKHEED ARC WELDING

Operators.—Both welders have recently prepared samples for the army standard tests which have been tested by an approved laboratory, and the men have been unofficially approved by the army inspector assigned at Lockheed aircraft factory.

Scope of Arc Welding Use.—It is used on parts of the landing gear and tail wheel assemblies which are practically all the heavy section welding jobs on the current models.

COMPARISON OF ARC WELDING AND THE FORMER METHOD

Arc welding is not easy to do and a fairly good operator is required to make a weld. However, a man can become a good arc welder in less time with less training and experience than is required for the former method because less knowledge of heat transfer and less judgment of heating and cooling conditions is required. It is much easier for a good operator to get a bad weld with the former method than with electrical equipment. With the former method, joining different thickness materials is increasingly difficult as the variation in thickness increases, but much less difficult with electric welding. With the former method, it is quite possible to place a layer of weld metal on a cold part which has the surface appearance of a good joint but practically no real adhesion. This is almost impossible with arc welding because if the arc occurs, the surface of the metal gets melted.

To appreciate the possibility of a bad weld that looks good, refer to Figs. 3 and 4. Fig. 3 shows a static tested landing gear fork. This structure had passed inspection and had the surface appearance of good welding. Failure occurred where the gusset of .125—4130 steel was welded to the tube of .120—4130 steel. The thickness of the metal is the same and not excessive for a weld and the weld should not have been difficult, but after failure, the tube was sawed in two and the crack spread to show the weld. Since a photograph does not show variations in tone very well, I had our artist very carefully touch up the actual failed metal with aluminum paint, which shows clearly as the thin white line in this picture. The darker grey behind shows parent metal which was not fused. The actual weld material varied from $\frac{1}{16}$ to $\frac{1}{64}$ inches and lay as a coating over the bad joint making it appear good. This condition is highly improbable in an arc welded joint for the reason stated above, and I have never seen anything approaching it.

It is more difficult to get a smooth joint of good appearance with an arc than with the former method, and an arc joint that is not good will be very evidently on the surface a bad job.

Tests of Welded Joints.—To compare the strength and fatigue properties of welded joints made by arc welding with those of joints made by the former method, five tests were run.

Test No. 1.—A joint was made as specified in Air Corps Specifications No. 20013-A-E-ZA, by the former method of welding. Another joint was made by arc welding by the same specifications except that the chamfer angle was 70° instead of 90°. Six specimens were cut from each sample, of which three were tested without heat treatment, and the other three were heat treated in the following manner.

The specimens were normalized at 1650° F. for thirty minutes, air cooled, reheated to 1550°, quenched in oil, tempered at 1000° for ninety minutes, and cooled in air. This heat treatment should give tensile strengths of $\frac{170,000}{150,000}$ lbs./in². The specimens were Rockwell tested to get an indication of the strengths obtained. The results are given in Table I, Page 133.

Test No. 2.—Two pieces of 1½ x .120 C.M. steel tubing, 5″ long, were chamfered at one end 45°, and welded together using the former method. Two other pieces, as above, were chamfered to 35° and arc welded.

Three specimens were made by each method. The excess weld material was turned off the outside surface in a lathe. One specimen of each was tested without heat treating. The other two were heat treated to $\frac{170,000}{150,000}$ lbs./in² as described under Test No. 1. All samples were Rockwell tested. One of these heat treated samples, and the unheatreated samples were tested in an Olsen Torsion testing machine. The third sample of each was saved for Test No. 3. Results of Test No. 2 are shown in Table II, Page 133.

Fig. 5. Tube, with plate welded at each end, in repeated shear testing machine.

Test No. 3.—A steel plate ¼″ thick was welded to each end of the samples and the tubes bolted into a machine, (See Fig. 5), so that the full throw of the eccentric was used in producing torsion in one direction. Therefore this test was a repeated shear test and not a test of reversed stresses. This machine deflected the arm .420 inches=2°5.56′.

$$T=\frac{E_s\,O\,J}{L} \qquad \begin{array}{l} J=(2)\ (.12478)=.24956 \\ O=.036534 \quad J/A=.33276 \\ L=9'' \text{ for arc weld} \\ L=9\tfrac{1}{4}'' \text{ for gas weld} \end{array}$$

$$\text{ARC} \quad T=\frac{(11{,}000{,}000)\ (.036534)\ (.24956)}{9}=11{,}143.5 \text{ in lbs.}$$

$$S_s=\frac{T}{J/A}=\frac{11{,}143.5}{.33276}=33{,}488\ \#/\text{in}^2$$

$$\text{Former Method} \quad T=\frac{(11{,}000{,}000)\ (.036534)\ (.24956)}{9.25}=10{,}842.3 \text{ in lbs.}$$

$$S_s=\frac{10{,}842.3}{.33276}=32{,}583 \text{ lbs./in}^2$$

The sample made by the former method stressed to 32,583 #/in² in shear stood 20 hours 10 minutes at 310 cycles per minute=375,000 loadings. Failure occurred by a crack ⅔ of the way around the tube in the middle of the weld material with a short longitudinal crack down the

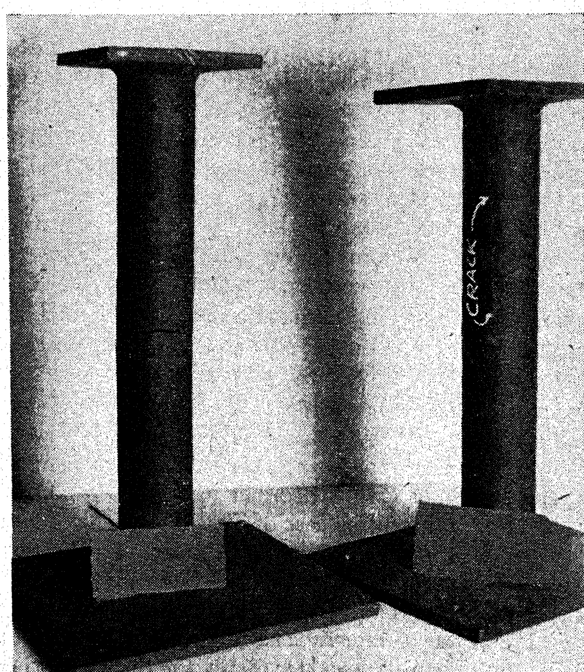

Fig. 6. Result of repeated shear test. Left—sample made by former welding method failed at weld. Right—arc welded sample developed longitudinal crack in the parent metal.

tube at each end of the circumferential crack. The tube was forced apart to examine the crack. The metal was coarsely crystalline in structure. The arc welded sample stressed to 33,488 #/in^2 in shear stood 27 hours 15 minutes at 310 cycles per minute=507,000 loadings. Failure occurred by a longitudinal crack in the parent metal from the weld to one end of the tube. The failure was not in the weld material. The two samples are shown in Fig. 6.

Test No. 4.—Twenty specimens as described in Test No. 2 were made using different welding rod. They were all tested as described under Test No. 2. Results of the test are shown in Table II, Page 133.

Test No. 5.—Eight specimens of 4130 tube 1½ x .120 x 9″ were tested as in Test No. 4. Three specimens were welded as described under Test No. 2 using SAE 4130 chrome-molybdenum steel welding rod, flux coated, using arc welding. Three specimens were welded by the former method using the same welding rod. Two samples of the tube without any welding, but heat treated the same as the other six specimens, were tested at the same time. The excess weld metal was turned off the outside of the welded tubes, and all eight specimens were heat treated as described under Test No. 1. Results of the test are shown in Table II, Page 133.

Samples No. 6, 4, and 5 of Test No. 1, (See Fig. 7), failed in the parent metal about 1½ inches from the weld. The edge of the specimens showed some elongation in the weld material, and considerably more in the parent metal at a distance from the weld, but there was a band about ¼ inch wide at each side of, and adjacent to, the weld which showed no evidence of distortion, and subsequent measurement with a micrometer indicated that these bands were not changed from their original width and thickness. This metal was stressed to 90,000 lbs./in^2 without reaching its yield point. This was due, of course, to the heat treating of the metal by the heat developed by the arc, and it shows the extent of the heating effect of arc welding. The weld material developed greater strength than the unheat-treated parent metal.

The heat treated weld samples made by the former method broke in the weld at an average stress of 63,980 lbs./in^2, but one of the three samples showed only 46,275 lbs./in^2. (See Fig. 8).

The tests show considerable variation in ultimate shear strength, but they show a definite superiority of arc welding. Since the manufacturers of arc welding rod do not state the composition of their metal, it is difficult to compare the rod used in the former method of welding with that used in arc welding, except in the case of Test No. 5. The average of the two unwelded tubes was 102,180 lbs./in^2 shear. The average of the three welds made by the former method was 79,390 lbs./in^2, or 77.7% of the average tube strength. The average of the three arc welds was 98,160 lbs./in^2, or 96.1% of the average tube strength. This shows the arc welds to be 23.6% stronger than the welds made by the former method. There was also greater uniformity in the arc welds as is shown by the greater variation from the average in the welds made by the former method.

Table I—Results Test No. 1

Sample No.	Type of Weld	Heat Treat	Tensile, Rockwell Indicated	Width	T At Weld	A	Ultimate Load	Ultimate Tension Stress	Failure
1	Former Method	None	93,800	.744	.244	.18154	Missed*		In Weld
2	Former Method	None	93,800	.7415	.245	.18167	10460	57,575	In Weld
3	Former Method	None	95,000	.742	.255	.18921	10670	56,390	In Weld
4	Arc	None	95,000	.742	.260	.19292	17550	90,970	In Parent Metal
5	Arc	None	95,000	.740	.260	.19240	17500	90,955	In Parent Metal
6	Arc	None	93,800	.740	.263	.19462	17480	89,815	In Parent Metal
7	Former Method	{170,000 {150,000		.733	.245	.17959	13000	72,387	In Weld
8	Former Method	"		.7375	.240	1770	12950	73,160	In Weld
9	Former Method	"		.7315	.243	.17775	8225	46,275	In Weld
10	Arc	"		.7315	.257	.18800	19225	102,260	In Weld
11	Arc	"		.736	.257	.18915	20850	110,230	In Weld
12	Arc	"		.7375	.257	.18954	19750	104,200	In Weld

* Failure occurred before it was expected and testing machine was not balanced.

Table II—Results Tests Nos. 2, 4, and 5

Sample	Weld	Tensile Rockwell Indicated	Pointer Reading			Ultimate Torsion	Ultimate Shear Psi	Ave	Variation %	Failure	Extent of Failure
					Twist						
Test 2- 1	Former Method		354*	18*	24*	15,730	47,300			Weld	Complete
2- 2	Arc					19,275	58,000			Weld	Complete
2- 3	Former Method		18	52	34	18,650	56,100			Weld	Complete
2- 4	Arc		65	93	28	23,960	72,000			Weld	Complete
Test 4- 1	Former Method	158,000	3	30	27	17,350	52,140			Weld	Complete
4- 2	Former Method							52,740	±11.4	Weld	Complete
4- 3	Former Method	173,000	218	239	21	17,750	53,340			Weld	Complete
4- 4	Former Method	158,000	57	88.5	31.5	26,110	78,465			Weld	⅔
4- 5	Former Method	158,000	300	335	35	30,150	90,605	81,900	− 4.3 +10.6	Weld	⅓
4- 6	Former Method	173,000	24	59	35	25,500	76,630			Weld	¾
4- 7	Former Method	154,000	333	3	30	29,050	87,300			Weld	Complete
4- 8	Former Method	153,000	103	138	35	26,670	80,150	85,740	− 6.5 + 4.9	Weld	½
4- 9	Former Method	173,000	115	144	29	29,870	89,765			Weld	¾
4-10	Former Method	150,000	60	85	25	19,350	58,150			Weld	⅚ Bad Spot
4-11	Former Method	154,000	271	300	29	22,570	68,370	63,860	+ 7.1 − 8.9	Weld	Complete
4-12	Former Method	179,600	130	159	29	21,650	65,060			Weld	Complete
4-13	Arc	162,800	49	88	39	29,570	88,860	91,460	± 3.9	Weld	¼
4-14	Arc	162,500	81	123	42	31,300	94,060			Weld	½
4-15	Arc	158,000	112	*		29,100	87,450	89,960	± 2.8	(Tube Buckled) (Near Support)	¼
4-16	Arc	150,000	80	132.5	52.5	30,770	92,470			In Weld	0
4-17	Arc	158,000	168	202	34	26,475	79,560	80,500	± 1 7	In Weld	¾
4-18	Arc	162,000	320	346	26	27,100	81,440			In Weld	⅚
4-19	Arc	158,000	91			31,500	94,660			(Tube Buckled) (Near Suppt.)	0
4-20	Arc	153,800	239	277	38	29,400	88,350	89,000	− 6.7 + 6.4	In Weld	½
4-21	Arc	158,000	202	233	31	27,950	83,995			In Weld	¼ (Slag incl.)
Test 5- 1	Arc		270	300	30	30,765	92,450	98,160	− 5.82 + 4.29	In & Across Weld	⅔
5- 2	Arc		16	52	36	34,065	102,370			In Weld	½
5- 3	Arc		39	70	31	33,160	99,650			(In & Adjacent) (To Weld)	¾
Test 5-X	Former Method		75	106	31	27,510	82,670		+ 4.13	Weld	Complete
5-XI	Former Method		98	127	29	27,325	82,120	79,390		Weld	95%
5-XII	Former Method		123	148	25	24,420	73,385		− 7.56	Weld	95%
A	None		51	318	267	34,225	102,850	102,180		Twist Near Clamp	
B	None		127	87	320	33,780	101,515			Tube Split Twist & Buckle	

The best welds made by the former method showed a variation from average strength in three samples of $^{+10.6\%}_{-\ 4.3\%}$. The best arc welds showed a variation of $^{+4.29\%}_{-5.82\%}$ in three samples.

Most of the weld samples made by the former method failed by complete shearing off of the tube. Most of the arc welded samples failed by cracking only part way, with the tube still taking some load. Fig. 9 shows the comparison.

Since cost is relatively unimportant as compared with strength and reliability in an airplane structure, no great emphasis has been placed on the cost of arc welding as compared with the cost of the previous method. However the average welding time using the former method was 16 hours. The structure is now welded by the arc in 8 hours average showing a saving of 8 hours at \$2.50 per hour factory cost=\$20.00. There are two of these forks used per airplane which makes a saving of \$40.00 per airplane.

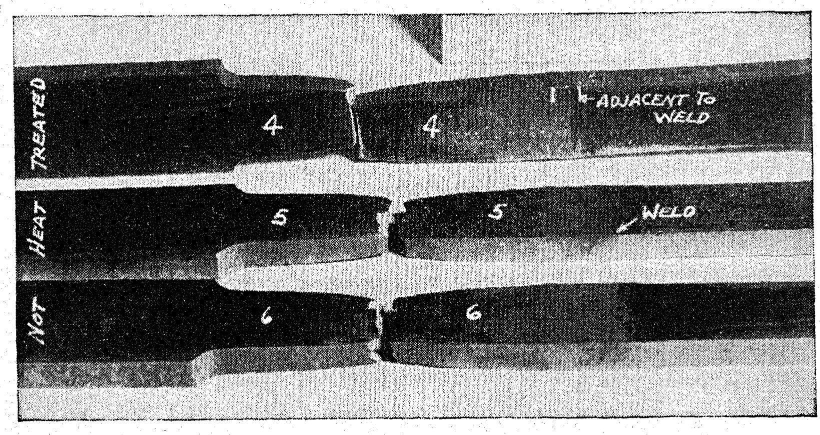

Fig. 7. Arc weld metal showed greater strength than the un-heat-treated parent metal.

The greatest saving resulting from the use of arc welding on this particular structure, has been in the fact that the method is now used on many other structures which would each show a comparable saving in welding cost, and some would show greater savings in that the machining and jigging cost is reduced, and easier fit obtained due to the freedom from warping obtained by arc welding rather than former welding.

This paper is submitted in the hope of making the benefits due to arc welding more available to the entire aircraft industry. At the present time the use of arc welding is restricted by the Bureau of Air Commerce. Quoting from Civil Air Regulations 04—Airplane Airworthiness, paragraph 04.4011, "Torch Welding—Torch welding of primary structural parts may be used only for ferrous materials and other materials shown to be suitable therefor." Paragraph 04.4012, "Electric Welding—Electric Arc, spot or seam welding may be used in the primary structure

when specifically approved by the Secretary for the application involved. Requests for approval of the use of electric welding shall be accompanied by information as to the extent to which such welding is to be used, drawings of the parts involved, apparatus employed, general

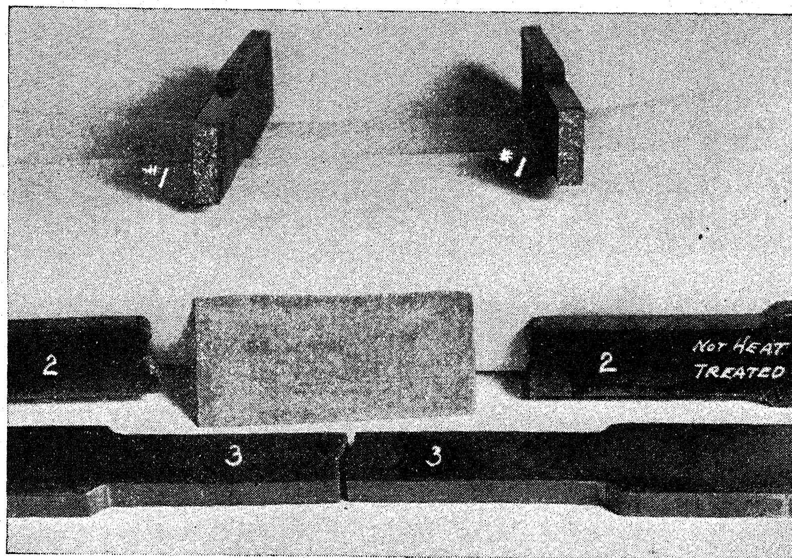

Fig. 8. Sample made by former method failed at heat-treated welds.

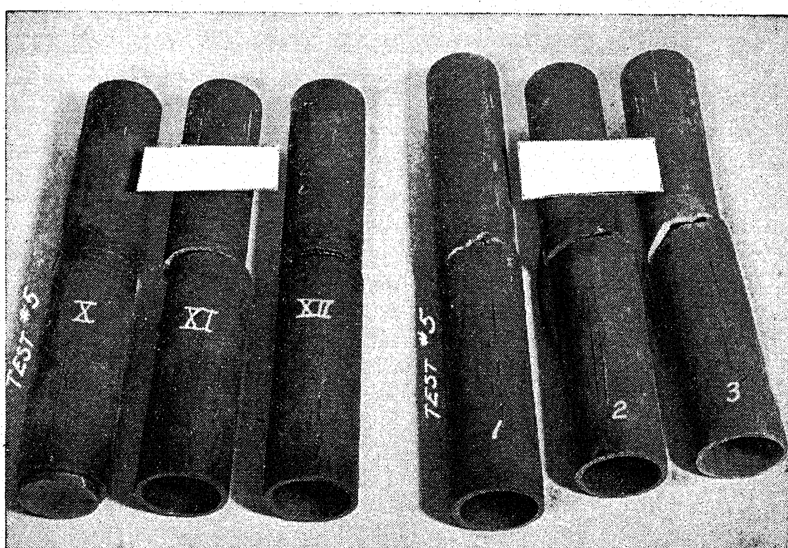

Fig. 9. Three samples at left, (X, XI, and XII), made by former method sheared completely off at welds. Arc welded samples failed by cracking only part way.

methods of control and inspection, and references to test data substantiating the strength and suitability of the welds obtained."

There is no reason why arc welding should be restricted by this regulation which puts it in the same class as spot and seam welding, for in the opinion of this writer, arc welding is a better method of joining "ferrous materials or other materials shown to be suited therefor" than other forms, and the regulation covering arc welding should not be any more rigid than that covering torch welding. It is believed that the tests submitted herewith substantiate that opinion. These tests were made to submit to the Bureau of Air Commerce to obtain approval of arc welding. The Welding Specification was made to conform with the standard of the Bureau of Air Commerce. In the writer's opinion, the Specification is unnecessarily rigid, and the qualifications of aircraft welders alone would be sufficient to obtain good welds. However, in order to obtain approval of the Bureau of Air Commerce, in the future the drawing will indicate where arc welding will be used by showing this specification number.

Chapter V—Design of an Outer Wing Panel for Large Airplanes

By W. E. Savage and J. B. Johnson,
Aeronautical structural engineer and chief, material branch, respectively, U. S. Army Air Corps, Wright Field, Dayton, Ohio.

The design of a single shear web outer-wing panel for large aircraft is the subject of this paper.

The design employs a single spar fabricated from heat treated alloy steel, arc welded, which takes the bending and shear loads, and a nose section of stainless steel, spot welded, which absorbs the torsional loads on the wing. The rear section develops the shape of the airfoil but is low stressed and is fabricated from formers of stainless steel, fabric covered. This is the most practical structure for minimum weight and maximum strength and rigidity. The principle of this design can be applied to any large or medium sized aircraft not only to the outer wing panel but also to the center section.

The new and original features of this design are:

1. The combination of a welded steel spar and stainless steel nose section to form the primary structural element of the wing.
2. The use of arc welded heat treated steel for a wing spar.
3. The use of arc welding after heat treatment to produce a structure which is economical and practical to build without limitation on size.
4. The initiation of a type of construction which can be built with the materials now available but has unlimited possibilities with improvement in these materials.
5. A lower weight per square foot to build than any other type of construction.
6. A lower cost per square foot to build and a lower maintenance cost than any other type of construction.

The design of large airplanes and seaplanes permits applications of materials and methods of construction which were difficult to use and not always economical and practical in the case of smaller aircraft.

Fusion welding is well established in the airplane industry. It is used extensively for joints in fuselage, wing, engine mount, and landing chassis. Large assemblies, such as fuselages and engine mounts, are welded from normalized steel in the "as received" condition and used without further heat treatment. Smaller components, such as landing struts, axles and wing fittings, are welded and heat treated after welding. Wing spars for the smaller airplanes are also made in this manner. The heat treated aluminum alloys are superior to normalized steel for the construction of wings and fuselages for large airplanes, and only if steel with higher mechanical properties can be used is this advantage overcome, and the strength-weight ratio becomes favorable to steel.

Several attempts have been made in foreign countries to adapt a heat treated alloy steel strip to airplane construction. The strip is heat treated prior to fabrication and assembled with riveted joints. It is difficult to drive sufficient rivets in the small space available to obtain an efficient joint and this type of construction has never been adopted on a large scale, nor has it received much consideration in the United States. The heat treatment of large components after welding by quenching and drawing is a very difficult and expensive procedure, and in fact for the larger airplane, impossible, due to the size of furnace equipment necessary and the spoilage which may result due to warping and cracking during the quenching operation. Electrical resistance heating is not feasible on account of the joints.

The advantages of heat treated construction can be obtained easily and economically if the parts can be heat treated before assembly and welded in this condition. This is a practical method. It has been used for a few highly stressed components, such as fuselage bulkheads in small airplanes, and the service life and maintenance of these airplanes has proved that it is sound engineering practice if properly carried out. Ultimate tensile strengths up to 150,000 pounds per square inch have been used in such parts satisfactorily.

A similar procedure can be used for other components and will be of greater value as the size of airplanes increases. It makes possible the construction of fuselage and wing components with strength-weight ratios superior to any type in service at the present time.

It is more difficult to meet the necessary low weight requirements in the design of an outer wing panel than in the case of a center section or fuselage and hull. For this reason the design of an outer wing panel with a 60-foot span which is suitable for any large bombardment or transport aircraft has been selected to demonstrate the application of arc welding. The principles of design developed for this outer wing panel may be applied to the design of the center section and other components of the aircraft, and may be modified for application to larger or smaller aircraft.

A low moment airfoil with a single spar (shear web) construction is used.

Materials.—The materials available for the construction of large airplanes are aluminum alloys, cold rolled stainless steel, and heat treated alloy steel. These materials are selected on the basis of: (1) Availability in the forms suitable for structural applications; (2) Strength-weight ratio; and (3) Ease of fabrication.

The aluminum alloys and heat treated steels are available in the many forms used in engineering construction. Stainless steel of high tensile strength, 185,000 pounds per square inch, is available only in the form of relatively thin sheets.

The strength-weight ratio of aluminum alloys, except for the fatigue strength, are superior to steel unless the latter is heat treated to a high tensile strength, in which case both the ratios in tension and compression, short columns, are favorable to steel, (See Table I). The elastic properties of a quenched and tempered alloy steel are much superior to those of a cold rolled stainless steel for highly stressed members. The basic values used for these data are published in the Handbook A-N-C 5, "Strength

of Aircraft Elements," issued by the Army-Navy-Commerce Committee on Aircraft Requirements, Jan. 1938.

TABLE I—STRENGTH-WEIGHT RATIO—TENSION

	Heat Treated Duralumin (24ST) Sp.Gr. 2.78		Heat Treated Steel X-4130 Sp.Gr. 7.85				Cold Rolled Stainless Steel 18 Chromium 8 Nickel Sp.Gr. 8.0	
		Ratio	Normal-ized	Ratio	Quenched and Drawn	Ratio		Ratio
Ultimate tensile strength, per square inch......	62,000	22,000	90,000	14,000	180,000	23,000	185,000	23,100
Yield strength, per square inch	42,000	15,000	70,000	8,900	165,000	21,000	140,000	17,500
Fatigue strength, bending, per square inch......	14,000	5,000	45,000	5,700	90,000	11,400	75,000	9,400

General Design Criteria.—The primary structural element of the wing panel, Figs. 1 and 2, is built into the leading edge of the wing and continues back 30 per cent of the wing chord. At 30 per cent of the wing chord, Figs. 2 and 3, is located the arc welded steel tubular truss which, together with corrugated stainless steel and smooth sheet covering of .010 inches in thickness forward of the truss, forms the primary structural element of the wing. The corrugations in the stainless steel

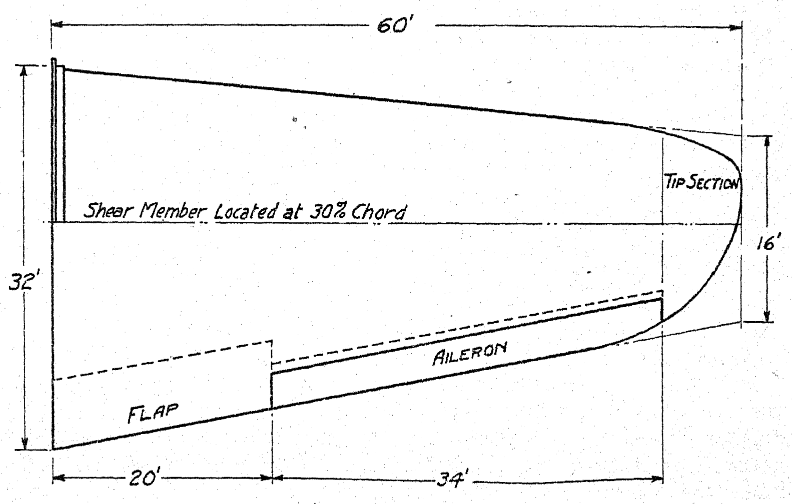

Fig. 1. Airplane wing plan form.

run spanwise. This corrugated sheet is formed to the contour of the nose section of the airfoil and attached to the upper and lower flanges of the arc welded truss.

The primary structural element described above resists the shears and moments due to beam and chord forces and the moments due to torque.

Outer Wing Panel for Bombardment or Transport Type Airplanes.

Span	60 feet
Root Chord	32 feet
Tip Chord	16 feet
Area	1440 sq. ft.
Wing Loading	30#/sq. ft.
Positive Design Load Factor	5.5
Negative Design Load Factor	—3.0
Maximum Positive C_n	+1.4
Maximum Negative C_n	—1.2
Sharp Edge Gust	36.75 ft./sec.
Assumed High Speed of Airplane	250 m.p.h.
Assumed Terminal Velocity of Airplane	600 m.p.h.
Diving Speed (Operating)	1.10% of high speed.
Diving Speed (Design)	1.35% of high speed.
Wing Root Thickness	18%
Wing Tip Thickness	9%
Airfoil	NACA 23018-09

The arc welded steel tubular truss which is 69 inches deep at the root and 17 inches deep at the tip is built of short lengths of round tubing. The maximum length of any tube is 7 feet. Round tubes are ideal for compression members. The curvature of the wall and absence of free edges give a member which will have greater stability for less weight than a component assembled from sheet and rolled sections such as stainless steel, and which fails by local crinkling. Each length of tubing is upset at each end to a wall thickness 80 per cent greater than the original wall thickness in order to compensate for the reduction in strength due to the higher drawing temperature at the ends and the effect of the heat of welding. The increase in wall thickness of the tube, resulting from the upsetting operation, is accomplished by reducing the inside diameter of one tube and increasing the outside diameter of the mating tube. By this device the size and weight of the web flange will be progressively reduced from the wing root to the tip without requiring the use of the more costly tapered tubing. The length of the upset portion of the tube is sufficient to accommodate the welding of the gusset which forms the attachment of the spar flange, vertical member and diagonal member. The taper from the upset portion of the tube to the original diameter has a length equal to approximately the radius of the tube.

The design of the truss is such that the size and lengths used will permit heat treatment without special heat treating equipment. The tubes are in the short column or Johnson range. The thickness of the wall of the tubular columns is great enough to permit heat treating to 180,000 pounds per square inch without lowering the elongation of the material below 10%. The ends of the tube are drawn back to a tensile strength of 150,000 pounds per square inch to obviate the formation of

cracks in the base metal during welding. The heat treated tubular components for the flanges and web members of the spar are joined by means of heat treated gussets and finger patches.

In the design and construction of the primary structural element only chrome-molybdenum (X-4130) steel tubing, gussets and finger patches heat treated to 180,000 pounds per square inch and 150,000 pounds per square inch, respectively, and stainless steel (18-8) cold worked to 185,000 pounds per square inch are used. By using steel throughout, the stresses due to a temperature change of 100 degrees may be neglected. The members that make up the truss designed with a fixity coefficient of 2, which has been established as a reasonable figure.

The rear portion of the outer wing panel is a truss type, constructed of stainless shapes drawn from high tensile cold rolled strip, spot welded, and covered with fabric in order to keep the weight to a minimum.

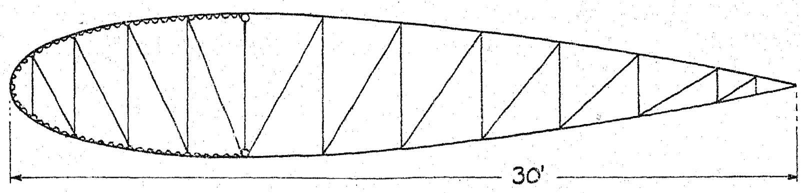

Fig. 2. Cross-section of airplane wing.

The necessary computations to make a structural analysis of the outer wing panel are not given due to the large number of engineering hours involved in the detailed calculations. However, the estimated weight of this outer wing panel is 3.5 pounds per square foot which is reasonable and light for a panel of this size when the design conditions are considered.

Detail Design.—This design has been simplified by using one type of joint for all panel points. This design is shown in Fig. 4. The principles used in this design are briefly—

a. A tensile strength of 150,000 pounds per square inch for all sections welded after heat-treatment.

b. Upsetting so that uniform strength is obtained the full length of the member.

c. Gusset and patch plates to develop the full tensile strength of the truss members at the panel points.

d. Large radii on patches and staggered gusset attachments so that the full compressive strength of the tube is obtained and the concentrations of stress due to vibration are reduced to a minimum.

e. Selection of arc welding to reduce the length of the upset section

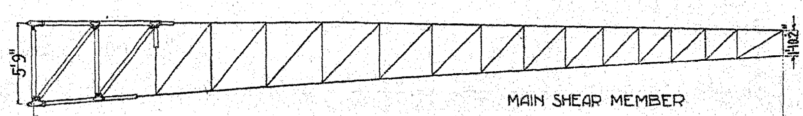

Fig. 3. Main shear member.

of the tube and the size of the joint. Without this refinement the weight would exceed other forms of construction.

These principles are applicable to the design of all joints. The complete stress analysis of the joint at the panel point adjacent to the root section of the wing is given below. This is analyzed in accordance with the practice established by the Army-Navy-Commerce Committee on Aircraft Requirements as published in the Handbook ANC-5, "Strength of Aircraft Elements," Jan. 1938, Section 4.511: Welded Joints.

Allowable Loads for Welded Seams.—The allowable load on the weld metal in welded seams can be computed from the following formulas:

Chrome-molybdenum steel $\qquad P = .48\ Lts$ ....(4.7)

where P = allowable load, lbs.
- L = Length of welded seams, ins.
- t = thickness of thinnest material joined by the weld in the case of lap welds between two steel plates or between plates and tubes, ins.
- t = average thickness in inches of the weld metal in the case of tube assemblies. (Cannot be assumed greater than 1.25 times the thickness of the welded stock).
- s = 90,000 per sq. in. for material not heat treated after welding.
- s = ultimate tensile stress of material heat treated after welding but not to exceed 150,000 per sq. in.

Flange Member

Dia. of larger tube	3 inches—wall thickness .120 inches.
Heat treatment	180,000 pounds per sq. in.
Tensile strength	= 195,500 pounds per sq. in.
Heat treatment upset end	= 150,000 pounds per sq. in.
Tensile strength	= 287,000 pounds per sq. in.
Length of butt weld	= 9.4 inches.
Length of patch weld	= 9.0 inches.
Length of gusset plate weld	= 5.0 inches.
Strength of butt weld	= .48×9.4×1.25×.216×90,000
	= 110,000 pounds.
Strength of fillet weld	= .48×14×.216×90,000
	= 131,000 pounds.
Total strength of joint	= 241,000 pounds.
Margin of safety	$= \frac{241{,}000}{195{,}500} - 1 = .23$

Vertical Member

Dia. of tube	2.5 inches—wall thickness .120 inches.
Heat treatment	180,000 per sq. in.
Tensile strength	161,500 pounds per sq. in.
Square section	— same area as round section.
Heat treatment	150,000 per sq. in.
Tensile strength	= 234,000 pounds per sq. in.
Length of patch weld	= 9 inches
Length of gusset plate	= 9 inches
Total length fillet weld	= 18 inches.
Strength of weld	= .48×18×.216×90,000 = 168,000 pounds.

$$\text{Margin of safety in square tube} = \frac{234{,}000}{161{,}500} - 1 = .45$$

$$\text{Margin of safety in welded joint} = \frac{168{,}000}{161{,}500} - 1 = .04$$

Diagonal Member	
Dia. of tube	2.5 inches—wall thickness .120 inches.
Heat treatment	180,000 pounds per sq. in.
Strength	161,500 pounds per sq. in.
Square section	— same area as round section.
Heat treatment	= 150,000 pounds per sq. in.
Tensile strength	= 234,000 pounds.
Length of patch weld	= 12 inches.
Length of gusset weld	= 12 inches.
Total length of fillet weld	= 24 inches.
Strength of weld	$= .48 \times 24 \times .216 \times 90{,}000$
	= 224,000 pounds.
Strength of gusset plate	$= (.25 \times 3 + .216 \times 2)\ 150{,}000$
	= 177,300 pounds.
Margin of safety	$= \dfrac{177{,}300}{161{,}500} - 1 = .10$

The margins of safety are all positive so that the design conforms to the requirements for strength as established by the ANC Committee.

Detailed Fabrication.—The tubes are upset at the mill and delivered in the normalized condition. The subsequent operations are—

1. Machine bevel for butt weld.
2. Machine slots for gussets, leaving radius at end of slot equal to ½ width of slot, to prevent cracking during heat treatment.
3. Arc weld attachments for nose section and ribs to tubes.
4. Heat treat by quenching in oil from 1600° F. and drawing at approximately 750° F. to develop a tensile strength of 180,000 pounds per square inch. Rockwell C—39 to 42.
5. Redraw the ends of the tubes in lead or salt bath at approximately 900° F. to 150,000 pounds per square inch, Rockwell C—32 to 35, to avoid possibility of cracking base metal during subsequent welding.
6. Install in welding jig and butt weld with metallic arc. Build up a bead approximately 25 per cent of the thickness of the base metal.
7. Set gusset plates which are heat treated to 150,000 per square inch in place and arc weld on one side only with a fillet weld.
8. Tack the truss members to the flange members with metallic arc.
9. Preheat to 350 to 400 degrees F. to avoid cracks in the base metal adjacent to the weld. This operation may not be necessary unless the material in the patches exceeds ¼-inch on future designs.
10. Arc weld the reinforcing patches which are forgings heat-treated to 150,000 lbs. per square inch, to the flanges and verticals and diagonal members of the truss.
11. Arc weld the short sections of heat treated nose attachment members to joint. These sections will have ample strength heat-treated to 150,000 lbs. per square inch.
12. Magnaflux for cracks.
13. Fill the inside of the tubes with hot linseed oil and drain.
14. Plug open ends of flange tubes to prevent entrance of water.
15. Spray outside of spar with aluminum spray for corrosion resistance.

The metallic arc welding process is selected in preference to other forms of fusion welding for the joining of the heat treated steel parts for the following reasons:

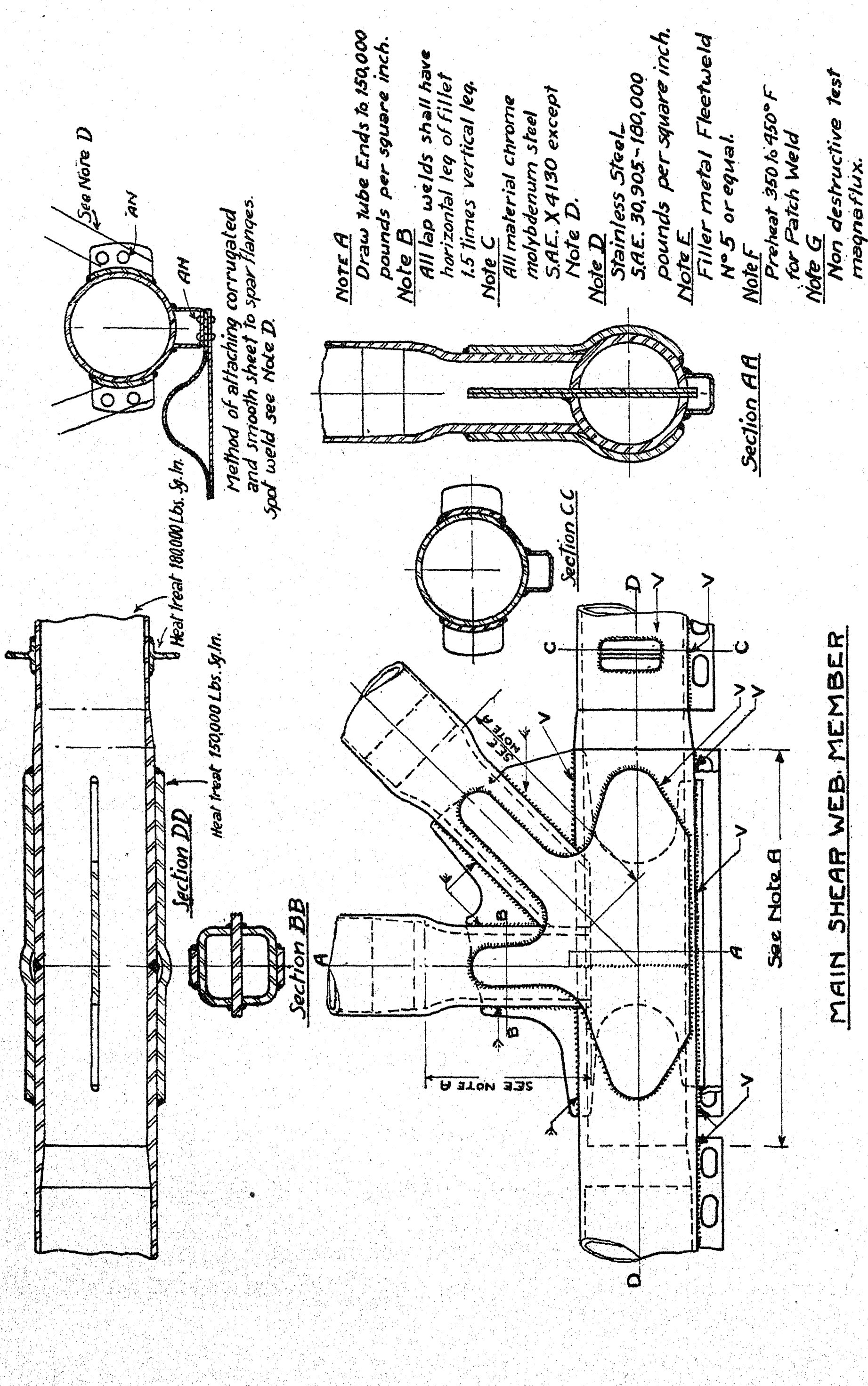

Fig. 4. Details, main shear web member.

1. The zone of base metal affected by the heat of welding is narrower.

2. The time of exposure to the heat of welding is less so that grain coarsening and decarburization are reduced, and to a large extent eliminated.

3. All the filler metal is laid down in one pass.

4. The weld metal has better mechanical properties, i.e., ultimate strength and ductility.

5. The reliability of metallic arc welding has been demonstrated by several years' service in all types of airplanes. It is used extensively in the joints of engine mounts which are subject to more vibration and greater amplitude of vibration than any other component in the airplane.

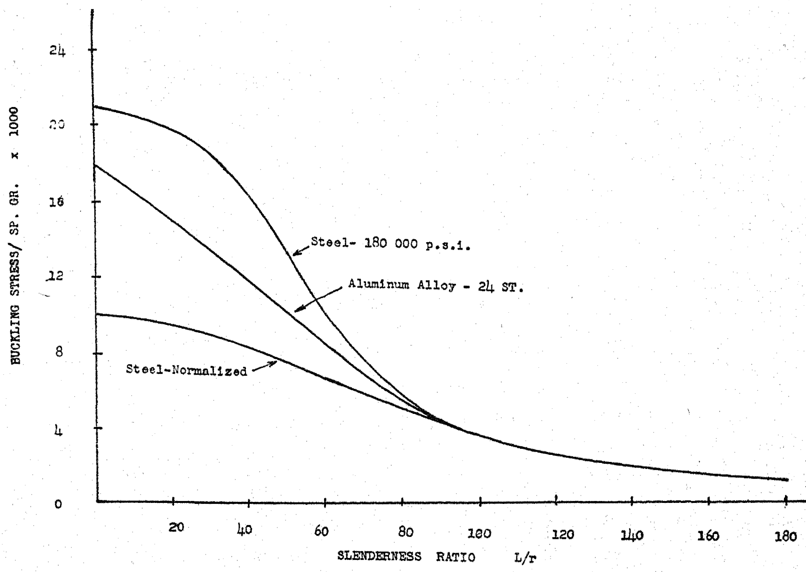

Fig. 5. Graphs showing effect of heat of welding. Tests made on butt welded joints in chrome-molybdenum steel sheet, previously heat treated.

The effect of the heat of welding is shown in Fig. 5. The tests were made on butt welded joints in chrome-molybdenum steel sheet, X-4130, which had been previously heat treated as indicated on the graphs. The Vickers Diamond hardness numbers were obtained on the top surface of the joint at intervals of $\frac{1}{16}$ inch.

The width of the zone affected by the heat of welding is also indicated. In the case of the welds in steel of 150,000 pounds per square inch the width of the zone of the arc welded joint is only 40 per cent of that of the oxy-acetylene joint. (See Fig. 6).

Arc welding of thin metal in relatively small sections when the arc must be broken frequently due to change in direction has indicated no advantage over conventional welding, but it does have a distinct advantage when the metal becomes thicker and the joints become larger. This is not solely a theoretical consideration, but has found practical application. Struts and axles are welded in the normalized condition and heat-treated

to develop a tensile strength of 180,000 to 200,000 pounds per square inch. The expansion which takes place on torch welding often starts small cracks which are not visible on the assembly before heat treatment. When these cracks are discovered after heat treatment it is an accepted practice to reweld the crack with the metallic arc and use the landing gear without further treatment.

Cost.—The cost of construction is not usually the deciding factor in selecting the type of design to be used for transport or military aircraft. The savings which accrue in the form of increased performance and pay load will more than offset the initial cost of many refinements which would not be considered in other engineering structures.

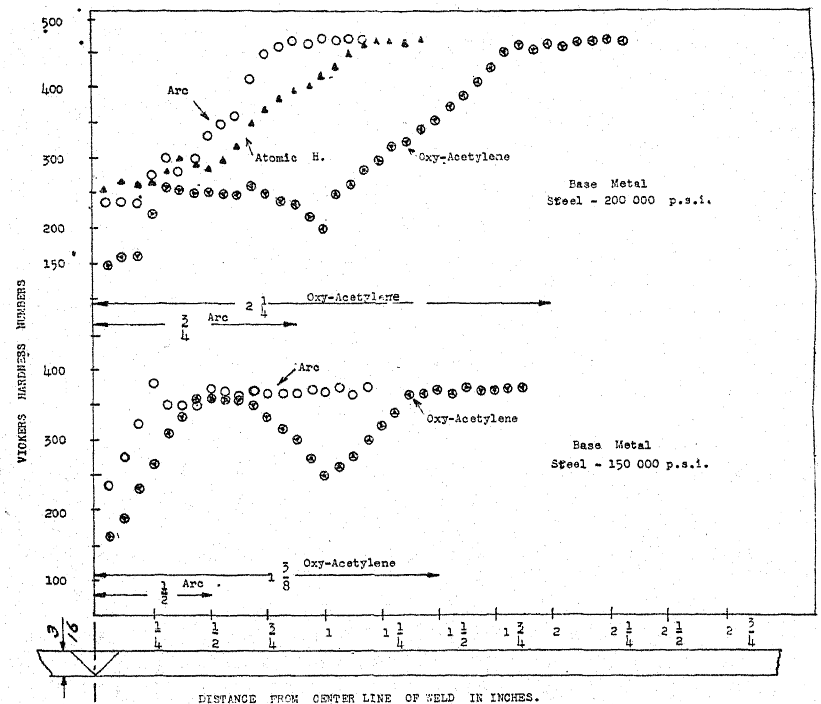

Fig. 6. Graphs show width of zones affected by heat of welding.

Furthermore, the construction of aircraft has never reached the stage where the methods used in the automobile industry for lowering costs can be applied. The purchase and scrapping of machinery over short periods of time is not justified on a production limited to 100 to 150 articles per year. Each job is custom-built.

However, reduction in the costs is always desirable and is achieved by the design which is submitted. The most common form of construction is the wing panel in which the bending and torsional loads are carried in a box spar of a width equal to about 70 per cent of the wing chord and a shear web fore and aft. This construction in aluminum alloys involves

the driving of about 100 rivets per square foot and represents an average cost of $25.00 per ft. Stainless steel construction with spot welding instead of riveting has never been reduced to a production basis but experimental design indicates a cost of about $22.00 per sq. ft.

The wing with a single shear web is inherently less expensive and an experimental aluminum alloy wing indicates a cost of about $20.00 per sq. ft. The construction has a lower weight per square foot which reduces the material costs, and the type of construction is simpler, involving fewer parts and fewer joints.

The single shear web in aluminum alloy construction again involves riveting, which is always more expensive than welding. This has been demonstrated by the large increase in price of the riveted aluminum alloy fuselage compared to the welded steel tubular truss type.

The arc welded steel spar can be produced at a lower cost than a spot welded stainless steel beam. The heat treated spar will be lighter in weight and the material is less expensive.

The reduction in weight is due to the smaller deflections and higher allowable stresses for heat treated steel. The yield strength of the latter is 165,000 pounds per square inch compared to 140,000 pounds per square inch for stainless steel, (Table I, page 139), and if the proportional limits are compared with influence deflections at working loads, the discrepancy is still greater.

The construction of a stainless steel spar would require sheet in excess of $\frac{1}{16}$-inch in thickness. It is impossible to cold roll these thicker sheets to 180,000 pounds per square inch, which means a lower allowable stress and therefore more material in the spar. A spar of this type could be only partially spot welded on a stationary welder, the investment required for special resistance welders could not be justified. It would be constructed of many overlapping plates to produce the necessary tapering of the cross-section from root to tip of the wing and this involves welding on assembly with portable welding tips. This method is slow and costly. The arc welded joints are simple in design and easy to produce. It is estimated that this design could be produced for $18.00 per sq. ft. of wing panel. This represents the total cost of which 40 per cent is labor, 28 per cent overhead, and 32 per cent materials, which is very close to the accepted breakdown for cost of airplane construction.

Possibilities of Design.—The type of design which has been described is capable of much development in its application to large airplanes. The design, submitted, is based on the materials now available and in general use for metal airplane construction. However, it is not limited by this choice of materials. Chrome-molybdenum steel, X-4130, was developed, primarily, for use in the normalized condition in thin sections and for oxy-acetylene welding with low carbon filler rods. With these conditions imposed, the choice of base metal is strictly limited. For heavy sections and with alloy steel filler rods, X-4130 is not entirely satisfactory. In the case of thick sections it must be water quenched to obtain maximum tensile properties. This is a disadvantage as it causes cracks and distortion. Low carbon filler rod is relatively low in strength and does not respond to heat treatment. The proportion of alloy steel

filler rod to low carbon rod is very small on account of the cracking of the alloy weld metal on cooling.

The base metal is not so restricted for arc welding. The chemical composition may be varied over a wider range and in the case of filler rod is almost unlimited due to the use of fluxes which protect and refine the weld metal.

The opportunity for the use of a steel which can be heat treated to a tensile strength greater than 150,000 pounds per square inch and welded after heat-treatment must not be overlooked. Unwelded parts and parts heat treated after welding with tensile properties as high as 225,000 pounds per square inch are being used in airplane structures but the welding of the X-4130 steel in this condition is not practicable.

Arc welding can be used with greater facility for welding large heavy sections and is much better adapted to the welding of forgings to rolled stock.

Electrodes for airplane welding offer an excellent field for research. The electrodes used at present are commercial types developed for general purpose welding. Airplane welding is intermittent in character; the seams are relatively short and the arc must be pulled frequently and should not leave a weak spot in the deposited metal. The weld is practically always a single layer completed in one passage. Speed is not the most important consideration. The ability to make an overhead weld is usually not important. Ease of manipulation and stability of the arc are primary considerations. A short arc is desirable. The weld metal must be laid down accurately, smoothly, with approximately 25 per cent penetration of the base metal in the case of lap and fillet welds which are the type most commonly used.

Chapter VI—The Potentialities of Arc Welding in Airplane Design

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The fabrication of the airplane is essentially the building of a light-weight structure to a smooth, precise external form. In common with other structures, airplanes must also be sufficiently strong, inexpensive, durable, and efficient. Airplanes are designed to difficult specifications. Compromises must be carefully weighed. There is no leeway in which the designer may relax with a feeling of security. Consequently, costs have been high in comparison with those of less exacting forms of construction. Also, the volume of business has not justified the use of production machinery to any important degree. The airplane of today is largely a handmade article.

With the above points in mind, we shall investigate the application of the technique of arc welding to aircraft construction. We shall emphasize in particular the possibility of a reduction in costs, without a lowering of quality.

The application of arc welding to the stressed skin constructions in use at present offers a tempting field for development. The present technique is costly, a fact readily appreciated by study of Fig. 1. It involves setting up frames, bulkheads, or ribs in a jig at proper spacing and alignment. To these are attached the longitudinal stringers. Finally, flat, thin sheet metal skin is riveted to the stringers and frames. Because of weight requirements, structural design efficiency, and the necessity for compound curvature, thin gauges of skin are used, and it is attached by small rivets at very close spacing. The number of these rivets is tremendous.

The skin is literally sewed to the internal framework. The rivets may be of the flush type countersunk into the skin so as to leave a perfectly smooth external surface, or they may be of the round or brazier head types. Flush riveting is desirable from the standpoint of airplane efficiency, especially on the faster ships, but it entails considerable expense over ordinary riveting. The flush-riveted structure is an example of a compromise in which construction costs suffer appreciably for the sake of removing trivial-appearing rivet heads. At their worst, these rivet heads would project into the airflow for a distance of only one-thirty-second of an inch. This demonstrates graphically the extreme importance of good external form. It also shows how costs have grown as design has become more and more refined.

To emphasize further the economy of a refined external form, an interesting fact recently proved by research should be noted. It is

this: high speed air transports, when scrubbed free of dust, dirt, and grease at each landing, thereby having less air drag and reduced fuel consumption, will save enough on gasoline to pay for the scrubbing crew! Likewise, before the take-off of a soaring glider, it is common practice to go over the mirror-like wings with a duster.

Our object is to reduce costs, and to do it through the medium of arc welding. However, the mere reduction of manufacturing costs may not be economical in the light of the operation of the machine, when low cost is gained with a sacrifice in airplane efficiencies. Expensive forms of construction have been adopted in cases where the increase in first cost is quickly repaid in economy of operation. We seek economy in this broad perspective, and not in a restricted or temporary meaning.

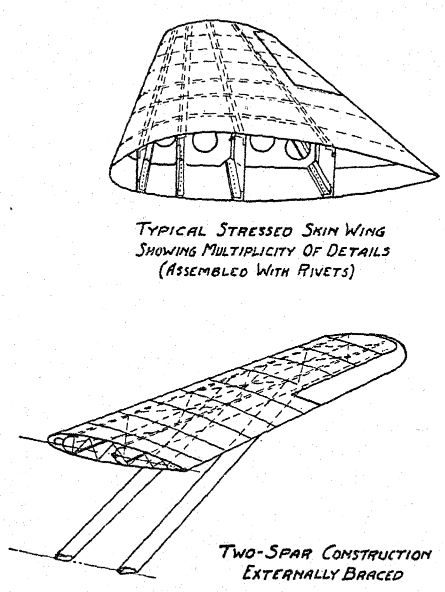


Fig. 1. Conventional airplane wing types show large numbers of details leading to expensive construction.

The outstanding expense item of present-day monocoque construction is the riveting, whether it is flush-riveting or otherwise. Rivet holes must be properly located in all the parts to be joined. Each rivet hole is drilled through with a hand drill, the rivet put in place, and individually headed. On large assemblies two men work together, one to back-up the rivet, the other to form the head. The labor costs are high and production is slow, resulting in a large plant overhead.

As to the relative costs of the skin, stringers, and frames, the stringers are by far the cheapest. They are extrusions, pound for pound

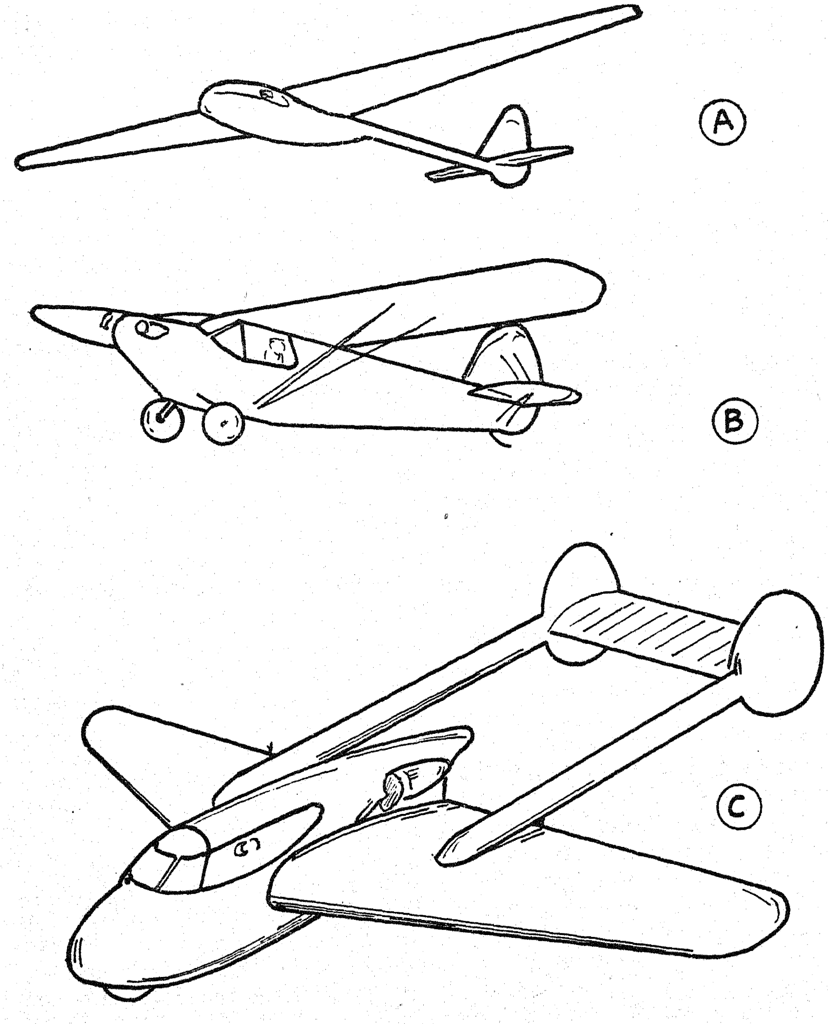
the least expensive form of aluminum alloy. They are assembled practically as purchased, except for incidental machining, and the gang-punching of rivet holes. The skin must be cut to the desired size and shape, the rivet holes punched, and in some cases it must be formed to curvature before being assembled on the ship. Bulkheads are more involved than either skin or stringers. Ordinarily no two are alike on one fuselage, they must always be formed, they waste large quantities of stock, which is trimmed off as excess, and they require elaborate forming dies. Thus, our search for economy in manufacturing the monocoque fuselage points to: (1) a simple assembly procedure to substitute for the laborious task of riveting; (2) the use of extrusions to as great an extent as possible; (3) the elimination or simplification of bulkheads and ribs; and (4), the use of simple skin patterns, preferably without previous forming.

Let us try a type of construction believed to be better adapted to welding than previous types, which is also simple from the standpoints of design, structural analysis, and fabrication.

The type of construction to which I refer, is the use, for major structural members, of fabricated steel spars. Steel sheet would first be rolled or pressed to form long shells of semi-circular cross sections. Two or more such shells would be placed with their concave sides inward to form a closed section, and would be arc welded along the seams. This would form a closed tube having arc welded longitudinal seams. The sizes and shapes of such tubular spars could be varied over wide ranges to accommodate the design being handled. Sections could be circular, oval, streamlined, or any other form. Such spars could be parallel-sided, or they could be tapered. The tapered spar, being only slightly more difficult to fabricate, and having distinct structural and aerodynamic advantages, would probably be the more common.

The spars would require only a means of forming the steel sheet, such as a press, or rollers, or even a simple brake, and arc welding equipment for making the joints. The arc welding equipment would preferably be automatic. Aside from the labor-saving, and the increased production made possible by the automatic welder, there is the further advantage of uniformity of weld. This is of primary importance in aircraft work. It makes possible the fabrication of welded joints of adequate and reliable strength without the use of oversized safety factors. Reliable and uniform welds mean weight saving. Also, welds which show uniform strength in test after test, inspire the confidence of designers. Therefore, the automatic welder is strongly indicated. In fact, this is one of the strong points of arc over other types of welding.

Tubular spars fabricated from thin steel sheet are not only easy to manufacture, but are also well adapted to airplane requirements. Most of the present-day aircraft structures are of the stressed-skin type Such structures seldom develop the full fiber stresses of the materials forming the skin. Instead, they fail by buckling and wrinkling. To prevent this buckling, and to distribute the stresses evenly into the skin, a great many bulkheads, ribs, webs and stringers are required, as mentioned earlier. Without these reinforcements, the stressed-skin struc-



Ⓐ A SAILPLANE, SHOWING "NACELLE-TAIL BOOM" FUSELAGE FOR LOW AIR DRAG
Ⓑ A MODEL TYPICAL OF THE POPULAR $1500 CLASS OF PLANE
Ⓒ THE DESIGN DESCRIBED HEREIN FOR FABRICATION BY ARC-WELDING TO COMPETE IN CLASS OF Ⓑ

Fig. 2. Stubby fuselages and tail surfaces carried on slender booms are efficient designs.

ture has insufficient local stiffness to hold its shape under load. If the skin is made heavy enough to do so, weights become prohibitive. Yet, the multiplicity of stiffeners prevents simplicity, either of design or construction. Stressed-skin design makes an entire wing, with its extensive cross section, serve as a beam. A single steel spar of very simple design could adequately replace this elaborately reinforced wing structure, with a large gain in simplicity of design and fabrication. This single beam must be sufficient to carry all the stresses. Moreover, it must be stiff. In such a design, deflections are likely to be the critical considerations. Therefore, steel, with its modulus of elasticity of nearly three times the figure for duralumin, would be a desirable material to use. Moreover, steel can be successfully welded.

The weight of such a wing would show up favorably, due to the economy of the design. One member does everything. It never relaxes while another member is temporarily taking the brunt of the load. The designer knows positively that this single member is carrying the entire load. There is no redundancy with the accompanying guess-work, duplication of effort, and conservative assumptions to cover the worst cases which the designer can imagine. This simplicity of analysis makes for light weight. No "ignorance factors" are required.

A considerable source of weight in design is the necessity of using members of specified minimum sizes. In lightly stressed designs the weight increase through this source is apparent. Therefore, the use of few members, highly stressed, is a weight-saving procedure.

In the early portion of this paper, considerable emphasis was placed upon the importance of good external form in airplanes. In view of this you may wonder why the use of steel spars is advocated. To a certain extent they will require external fairing, exactly as steel tube trusses required external fairing. The answer is found in a type of design having promising aerodynamic characteristics. It is described below.

Any airplane to be successful must be well streamlined. As aerodynamic forms become more and more refined, their air resistance becomes more and more a matter of skin friction. The more "wetted surface", the greater the drag. This is true of the well streamlined airplanes of today. A further reduction of drag may be accomplished by a reduction of surface areas, even when the streamline forms become relatively stubby. This line of thought leads to the conclusion that we may expect to see airplanes in the future with comparatively stubby fuselages, (See Fig. 2), and with the tail surfaces carried on slender booms. Such design has been in vogue for a number of years for sailplains (See A, Fig. 2), which are undoubtedly the most efficient aerodynamically of all forms of airplanes. "Nacelle-tail boom" arrangements have an added advantage of improved tail surface efficiency. The surfaces are located at a distance from the disturbing and blanking effect of a fuselage. They operate in relatively undisturbed air, and consequently are effective in their actions, as well as being relatively free from the possibilities of flutter or buffeting.

The arc welded steel spar is an ideal construction for tail booms. Thus, the backbone of the airplane would consist of tubular wing spars, and tubular tail booms, (See "C", Fig. 2). Add to this picture a pressed steel passenger nacelle of a stubby streamline form, built

in the manner of automobile bodies, and you have an idea of an economical and efficient type of airplane design, in which arc welding plays a large role.

There are many phases of this discussion which should be mentioned briefly at this point. In time of war, it is quite likely that deliveries of aluminum alloy, slow at best in peacetime, would be too

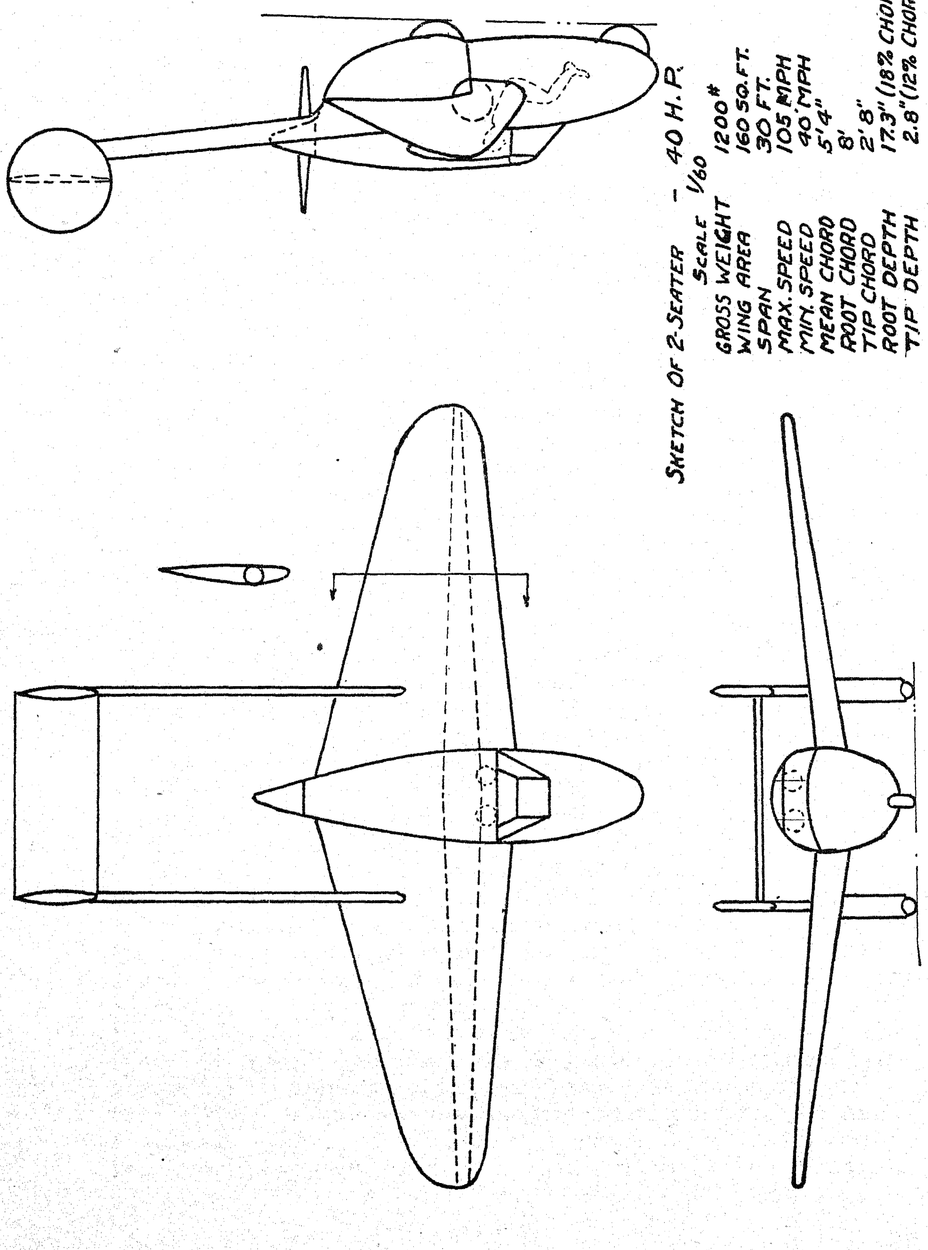


Fig. 3. Three-view drawing of plane having an arc welded monospar.

slow to meet the increased production of war-time demands. The military forces would undoubtedly welcome the development of a modern type of design which uses steel, and uses it effectively.

The use of tail boom designs fits in splendidly with the present revival of tricycle landing gears. A wide variety of types and sizes of aircraft suggest themselves for use with this construction. They all have the fundamental properties of manufacturing simplicity, along with structural and aerodynamic efficiency.

In order to illustrate the use of welded steel spars for the primary structure of an airplane, I am submitting a 3-view drawing, (See Fig. 3), of a type of plane which could be built to compete in the lowest price class of privately-owned planes. Planes of this class sell for about $1500. Present types are rectangular-winged, externally-braced monoplanes. Simplicity, or rather, frugality, is their keynote. They are reminiscent of the secondary gliders from which they sprung. A fully cantilever tapered-wing monoplane would be a surprising newcomer in this price class. It could sell for more than $1500, competing against more expensive types. It would have advantages of performance and appearance, made possible by the use of fabricated steel spars, which in turn, become economically feasible when fabricated by arc welding.

The airplane design shown in Fig. 3 is a 40 H.P. two-seater plane for private ownership. The data on performance, weights and areas, is given on the 3-view drawing. We shall consider in detail only the main wing spar, (See Fig. 4). This is for the purpose of proving the feasibility of an arc welded monospar design.

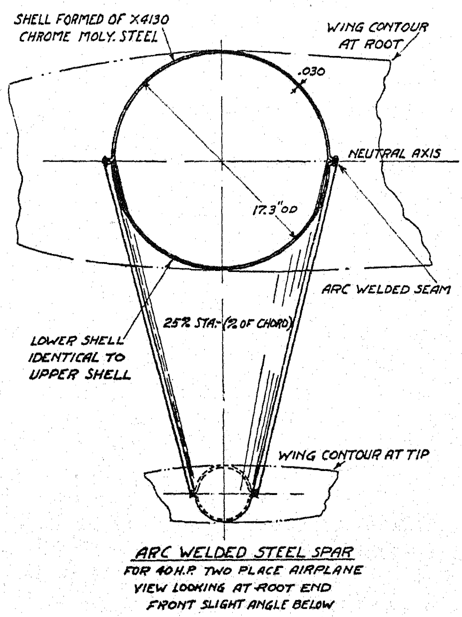


Fig. 4. Design of tubular wing spar for arc welding.

Averages of the weights of eleven actual airplanes have been studied. They show that the wings account for 14.5% of the gross weight, and that the wing spars, or equivalent structure, account for 8.5% of the gross weight of the airplane. The airplane used as an example weighs 1200 pounds. 14.5% of 1200 pounds is 174 lbs. Thus, the entire wings of our airplane will weigh about 174 lbs., as a reasonable first estimate. In the same manner, the spars alone should weigh 8.5% of 1200 lbs, or 102 lbs.

Using an allowable spar weight of 100 lbs., the problem is to design a tubular spar, and see whether it comes up to our design needs. (See Fig. 4). From the proportions of the airplane, we find that the wing root depth is 17.3 inches. Our spar section will inscribe a circle in this space, using the full depth. In the same manner the tip of the spar will just fill the depth of 3.8 inches, available at the wing tip. The area of a conical segment 15 feet long, tapering from a 17.3 inch diameter at the heavy end to a 3.8 inch diameter at the thin end, is 5960 square inches. This is the area of our spar on one side of the ship. We are allowed 50 lbs. of sheet steel to be spread evenly over this area. Chrome molybdenum alloy X-4130 steel weighs .283 lbs. per cu. inch. From these figures, we find that our steel sheet may be approximately .030 inches thick, without exceeding our weight limit. Thus, the root section of our beam is determined. For purposes of analysis, it is a circular tube of 17.3 inches outside diameter, with a wall .030 inches thick. The moment of inertia of this section, with a diameter as an axis, is 61 in^4.

The design bending moment at the root section, using a load factor of 8, is 364,000 inch pounds. From this, using the well-known formula for flexure of beams, $f = \frac{MY}{Io,}$ f is only 51,500 lbs/in^2. The allowable fiber stress of normalized X-4130 sheet is 90,000 lbs./in^2, which is more than twice the stress encountered. In heat treated forms, the tensile strength may be boosted to as much as 200,000 lbs./in^2. The yield point of normalized X-4130 is 60,000 lbs./in^2, which is safely above the stress produced. By heat treatment the yield point can be sent up all the way to 150,000 lbs./in^2.

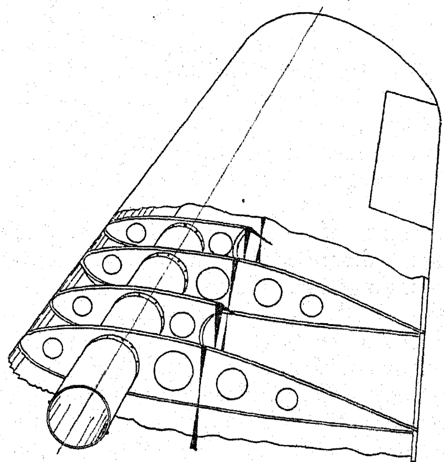
In torsion, the root section is subjected to a moment of 32,600 lbs./in^2 at an airplane diving speed of 250 m.p.h. The polar moment of inertia of the root section is 122 in^4. The shear stress developed by this loading is only 2300 lbs./in^2. This low figure demonstrates graphically the ability of this type of monospar to carry torsion.

From these few figures it follows that we are easily meeting our strength requirements. Actually, the beam is also carrying shear on this section so that the true case is not quite as favorable as it would appear by considering bending a torsion alone. The margins shown are sufficient, however, to make a bending-shear-torsion combined stress analysis unnecessary, for our purposes here. The only purpose of the analysis presented is to prove the feasibility of the structure. In that respect we have margins to spare, to do with as we please.

The deflection properties of such a cantilever monospar are worthy of consideration on a basis equal to its strength properties. Using the

formula $\delta = \frac{.44WL^3}{EI}$, where W is the total force on the cantilever, in pounds, L is the span of the cantilever, E is the modulus of elasticity, I is the moment of inertia of the root section, and δ is the deflection of the tip, in the same units as L is given. This formula is true for cantilevers subjected to elliptical loadings, having geometrically similar sections, all sections having the same fiber stress. It is derived from sailplane studies, and is conservative but useful for the usual airplane work. From this formula the tip deflection in level flight is .87″, a satisfactory figure. The beam meets both the strength and stiffness requirements.

The thin walls of this tube might be thought to be subject to local buckling, as in the case of monocoque structures. This point is settled when we realize that ribs are to be fitted over the beam to give the wing its airfoil shape. These ribs may easily serve the purpose of bulkheads. The fact that they are external to the spar rather than internal, makes no difference if they are stiff and properly attached. These bulkheads have the structural effect of reducing the column lengths of elements in compression, thereby reducing their buckling tendencies.



ASSEMBLY OF RIBS - SINGLE SPAR
SHOWING SIMPLIFICATION RESULTING
FROM USE OF ARC WELDED STEEL TUBE
SPAR (ASSEMBLY JIG NOT NECESSARY)

Fig. 5. Arc welded steel tube spar permits simplified assembly.

Enough for the structural design phases. Such a spar is feasible. The next step in proving the case for arc welding is to show that it will reduce costs. In this cost study, we must compare our arc welded spar with conventional design, and also with tubular spars fabricated with bolts and rivets.

The stressed skin wing of today, as built by Douglas, Northrop, Curtiss, and many others, has component parts of ribs running fore and aft, webs serving as beams running inboard and outboard, string-

ers lying between webs, and a covering of skin. The entire structure is riveted together. To prove our point, it should suffice to point out that the monospar replaces five or six webs, that the ribs in the two cases are roughly equivalent, that the monospar design has virtually no riveting, that assembly of ribs to a monospar is a simple procedure which does not require a jig, (See Fig. 5), that the attachment of a single beam to a fuselage is a simple matter when compared to attaching five webs, all of which must align perfectly. Once our frame is assembled, it is an easy task to stretch Grade A cotton cloth over it, and dope it. On the other hand, every piece on the monocoque job must be cut to exact pattern, so that all rivet holes are in alignment. Elaborate jigs are required. The task of riveting is a laborious and expensive one. Five cents per rivet is a figure often heard in estimating. The elimination of a single seam of rivets on a small sub-assembly in a recent contract saved a total cost of $12,000. Is a quantitative comparison necessary in the face of such costs? Where the numbers of parts and operations are large, costs will be high. Where design is simple, with few parts and operations, costs are low.

A two-spar construction is simpler to fabricate than the stressed skin multispar. Yet, it will require a drag truss, or drag bays of stressed skin. Two-spar designs in steel could be fabricated either by welding, or by rivets and bolts. Whatever is simple in this construction is one degree more simple with the elimination of one spar. The greatest rival in simplicity of the welded monospar is the bolted or riveted monospar. Either one of these is better adapted to low-cost production than more elaborate forms. Thus, in the last analysis, the cost question resolves itself to the technique of arc welding versus the technique of bolting or riveting.

In short, an advocate of bolting or riveting could take the design of welded tubular spar, described for the airplane above, and rivet all seams instead of welding them. Each of the two means could develop adequate strength. In the matter of weight, the welded structure possibly has a slight advantage, as the riveting and bolting flanges would require extra material, and the weights of bolts and rivets would be as great as the weld deposit. For our purpose the two designs will be considered equivalent, so that costs will be the only item to consider.

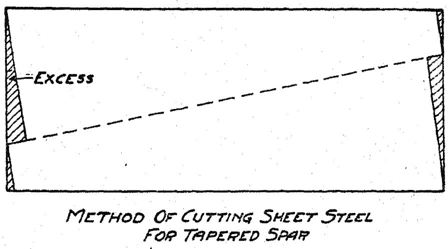
Factors entering into the costs are jigs and fixtures, forming machinery, labor, materials, power and tools, and plant overhead. Of these, the forming, (See Fig. 6), would be identical for both riveting and welding, so that item may be eliminated from the comparison. The others will be considered in order.

Jigs and Fixtures.—Both the automatic welding equipment, and the drilling operations require accurate holding of the beam while it is being assembled. Neither process has a distinct advantage here. The arc welding fixture has fewer points to be maintained with precision. It therefore would be somewhat less costly initially.

Labor.—The arc welded assembly has a very pronounced advantage here. Labor is one of the large expense items. All holes on the riveted assembly would be drilled by hand, and all rivets assembled by hand.

a laborious and slow task. No crew of men, no matter how large, could assemble the spar as rapidly as two or three men could operate the automatic welding equipment. This is a strong point for welding, and for arc welding in particular, with its reliable automatic processes.

Materials.—Again arc welding has a slight advantage. The pieces of sheet can be cut smaller for welding than for riveting, due to the need for a riveting flange. Also, welding rod is cheaper than the rivets and bolts required.



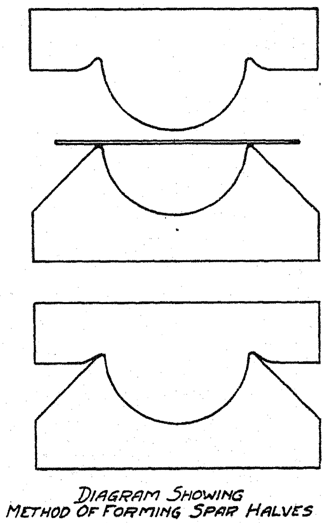


Fig. 6. Diagrams showing method of cutting steel sheet for tapered spar and method of forming spar halves.

Power and Tools.—This is a balance between hand drills and arc welding equipment, with no great margin for either.

Plant Overhead.—Here arc welding has a great advantage, due to the fact that one arc welding set-up can weld enough spars for a very large production of airplanes. The process is quick, simple, and direct. Riveting is slow and tedious, requiring large floor space.

The above shows definitely that the arc welded spar would be less expensive to fabricate than the riveted and bolted spar. The discussion is necessarily qualitative, because an accurate quantitative analysis demands that the part be fully designed for manufacture. In the aircraft industry, a great many actual tests would have to be made, and a great many approvals obtained, before it would become economical to undertake the detail design of an arc welded aircraft structure. Arc welding is new on airplanes. Processes would have to be adapted, and samples tested. The Army or the Navy or the Department of Commerce would have to approve the new technique. Careful preliminary estimates would then be made, to be followed by the actual design of parts. At such times accurate quantitative figures could be obtained

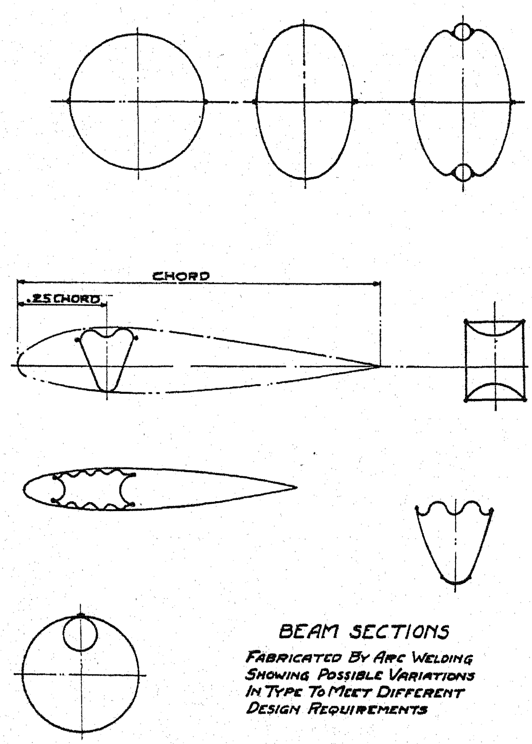


Fig. 7. Sketches showing possible variations of beam sections fabricated by arc welding.

To attempt to quote close figures at this stage would be to flatter the present status of the technique. Where accuracy cannot be obtained, the author prefers to remain qualitative.

The arc welded wing beams as described are only one phase of the spar construction using arc welding. A new aircraft production technique is opened by this type of construction. A sheet showing various beam sections has been prepared, (See Fig. 7). The construction would vary in accordance with design needs; whether for wing

spars, tail booms, elevator beams or elsewhere. The ship might be a 1200-pound two-seater as described, or a 200,000-pound Trans-Atlantic clipper. The advantages of the various sections will be apparent from studying the figures.

This discussion does not pretend to be a complete study into the use of arc welding for airplane manufacture. It is only a starting point. If it suggests possibilities to others, possibilities which ripen under continued investigation, and grow stronger, it will have been successful. Only the selective processes of time can help us to see more clearly, and to use our powers more intelligently. So it is with arc welding. Time will tell. Meanwhile, if this paper has proven anything worthy of notice, it is this: Arc welding has possibilities which no enterprising aircraft manufacturer can afford to ignore.

SECTION III

RAILROAD

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SECTION III

RAILROAD

Chapter I—New Design for Steam Locomotive Frame

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This paper describes a new welded design for a steam locomotive frame of plate type and draws comparisons with the corresponding design for riveted construction showing important economies in cost and in weight.

Many thousands of locomotive plate frames have been built by riveting and bolting and there is nothing fundamentally new in the riveted frame taken as prototype for redesign in this paper. So far as is known to the writer, however, no steam locomotive frame has yet been built entirely by welding. The subject of this paper has been chosen with this in view as acceptance by responsible engineers of the soundness of the welded design herein propounded should open a new and important field to electric arc welding.

Attention could have been given to the frame of some locomotive already in service to show how such frame could have been built better and more cheaply by welding but this savours of bolting the door too late. It has been considered more pertinent to take the case of a locomotive now actually in process of design in the drawing office of the railway employing the writer and show the economies possible by a re-orientation of the design. This brings the question into the realm of immediately practical politics.

In considering such a design it is essential that attention be given to the character of the workshops where the work will be done and to the facilities available. Railway workshops are principally engaged in maintenance of locomotives and rolling stock. Construction of new locomotives is not their principal function and it naturally follows that construction costs are likely to be higher than in shops specially arranged for that class of work.

For example, in this case all cutting with oxy-acetylene torch is done by hand by men paid higher than ordinary first-class tradesmen and the same applies to arc welding. Frame profiles are finished on a single-head milling machine whereas manufacturing shops commonly use multi-head slotting machines.

To avoid any chance inclusion of identifying marks all drawings relating to the original riveted design have been retraced.

Much attention has been given of late years to the question of residual stresses in welded structures and methods of stress relief. On this railway considerable experience has been gained in the use of the electric arc in large repairs to locomotive frames both plate type and bar type. In every case the use of "shielded arc" or "fully covered" electrodes has been insisted upon. Every weld is laid in short runs and thoroughly peened before the deposited metal has had time for consid-

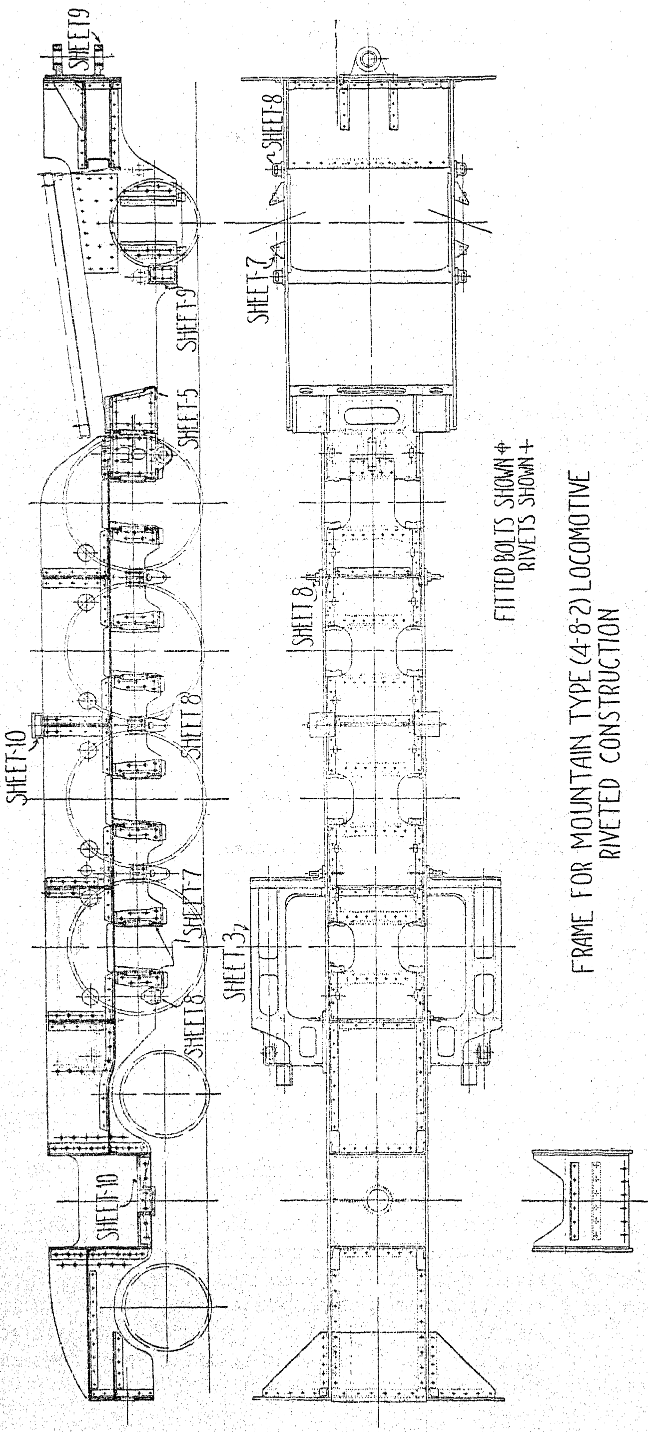

Fig. 1. General arrangement of locomotive frame for rivetted construction.

erable cooling and experience has afforded ample proof that this method gives all the stress relief needed. Very extensive arc welded repairs depending entirely upon the welds have been in service for many years without any sign of failure. This experience warrants the most complete confidence in the fully welded frame.

General Features of Locomotive.—This frame design is for a mountain (4-8-2) type locomotive to operate over 3′6″ gauge tracks. It is proposed to build ten of these engines with 19″ x 24″ cylinders and 4′0″ diameter driving wheels, a maximum axle load of 13 tons (29,120 lbs.) and 200 lbs. per square inch working pressure giving a tractive effort of 30,685 lbs. at 85 per cent working pressure. A wide firegrate for low grade fuel is provided and this necessitates special widening of the frame at the rear end to accommodate the ashpan. Walschaert valve gear is employed with a special intermediate lever to increase the valve travel. The fulcrum for this lever is incorporated in the machinery support structure.

Original Design of Frame.—In the original design, (See Fig. 1), endeavours have been directed to using a minimum number of steel castings with a view to reducing costs of patterns, marking-off, machining, and assembly, while securing a material reduction in weight. One casting is designed to carry the slidebars, valve gear, and reversing shaft in place of three commonly used and is designated machinery support. Axlebox guides (or pedestals) have been combined with frame stays instead of using separate castings for each function as is usual. The steel casting at the junction of the main and rear frames not only serves to join the frames but incorporates axlebox guides for the trailing coupled axle, main brake lever fulcrum, spring link brackets, and firebox supports. As a result, the design is relatively economical and provides less opportunity for further economies by adopting welded construction. This affords a further excellent reason for the choice of subject. Redesigns for welding should be compared with the best that can be done by other methods to show the benefits of welding in true perspective.

Welded Design.—In general, this design, (See Fig. 2), follows closely on the lines of the original design for riveting, there being little to gain by further departures from orthodoxy. One casting is employed. This is for the leading bogie pivot and as this pivot is not called upon to serve as a frame stay, an iron casting is suitable. There seems little scope for a more economical construction of this detail by welding as its shape is dictated by considerations not affecting strength or frame design.

The design incorporates all parts and attachments which may properly be regarded as permanent components of the frame structure. No attempt has been made to replace the cast iron cylinders, which incorporate the smokebox saddle, by a welded structure. It is considered that the cylinders should be regarded as separate entities and redesign for welding should be the subject of a separate paper. Of all parts of the locomotive the cylinders afford the least opportunity for improve-

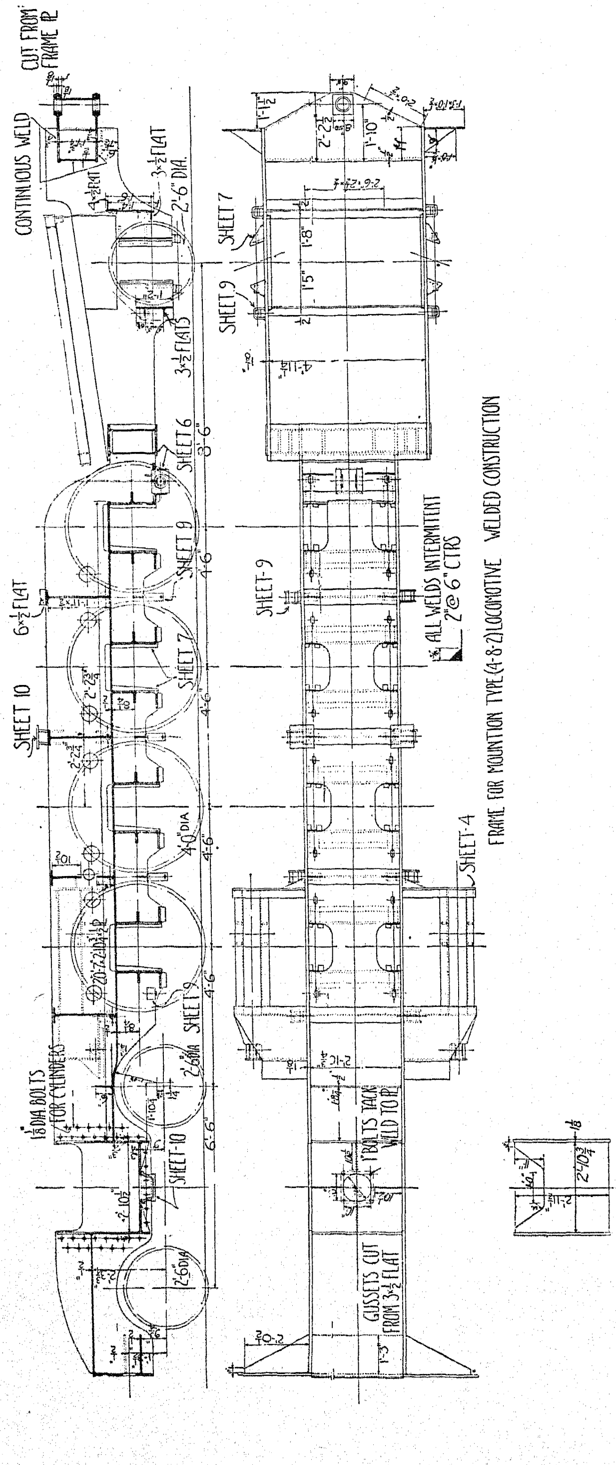

Fig. 2. General arrangement of locomotive frame for welded construction.

ment or economy by substitution of a welded structure by reason of their necessarily complicated shapes. Such designs of welded cylinders for locomotives as have been published follow very closely the lines of the pre-existing castings whereas a completely fresh viewpoint seems essential to success. It is felt that further discussion on the point does not properly belong to this paper.

Every design for welding in place of some other method of construction should be approached with a freshness of mind seeking the essential purposes of components rather than mere substitution. In the riveted structure the thickness of many plates and castings is dictated by a desire to afford reasonable bearing area for bolts or rivets.

There is not any doubt that this leads to the use of members heavier than necessary for essential strength. The absence of bolts and rivets in the welded design permits reduction in the thickness of some members and the saving in weight allows addition of other members to give a stronger construction.

It is usual, in riveted frames, to form large holes in plate and cast steel frame stays to eliminate some of the excess weight. In the welded design, the reduction in weight secured without such special measures is so great that the expenditure, inseparable from cutting holes in plates, may be avoided and the plates are shown solid. This certainly makes the structure a little heavier than is necessary but increases the gain in cost of construction.

The thickness of the frame plates themselves has not been reduced in the welded design. It could be argued that some reduction should be made as there is not any need to provide length of bearing for bolts save at the cylinder. In the writer's opinion, however, lateral rigidity is an essential quality of a locomotive frame and the material in the frame plates is situated almost ideally to afford rigidity. The practice of using flanged plates backed by angles as frame stays in riveted construction is well established. Cases of fracture in the root of the flange are not uncommon and this indicates bending pointing to the need for lateral rigidity. This fault is avoided in the welded design.

Observation suggests there is a common tendency to the use of welded fillets larger than necessary. Deposition of more weld metal than is needed is very wasteful indeed and in the use of a method of fabrication remarkable chiefly in its adaptability, economy and efficiency, such inefficiency should not be tolerated. Usually the size of fillets is based upon the thicknesses of the plates to be joined, but this is not necessarily a sound criterion. Close regard should be paid to the strength required in the weld and to the number and disposition of the welds resisting the forces imposed. In the case of the structure under consideration, a 3/8" fillet made with three runs of 1/4" electrode is amply strong as the welds are disposed to great advantage.

Drawings Submitted.—With this paper are the following drawings which show the two methods of construction very clearly:

Fig. 1. General arrangement of locomotive frame for riveted construction.

Fig. 2. General arrangement of locomotive frame for welded construction.

Fig. 3. Machinery support in cast steel.

Fig. 4. Machinery support in welded construction.

Fig. 5. Steel casting joining main and rear frames in riveted construction.

Fig. 6. Junction of main and rear frames in welded construction.

Fig. 7. Coupled axlebox guides (pedestals) in cast steel and welded counterparts.

Fig. 8. Spring compensating beam brackets, spring link brackets and brake hanger brackets for riveted construction.

Fig. 9. Spring compensating beam brackets, spring link brackets for welded construction, also steel castings for intermediate drawgear and frame stay in riveted construction.

Fig. 10. Steel castings for frame stay and boiler barrel support brackets in riveted construction also boiler barrel support brackets in welded construction.

It is proposed to deal with each of these drawings in turn, giving in each case an estimate of cost and comparisons of cost and weight for the two methods of construction. This will be followed by a comparison of assembly costs and total costs and weights. Throughout costs are given in Australian currency and in United States of America dollars at the official exchange rate of $3.99—£1.0.0.

Factual Data for Estimating Costs.—Wages of men employed in the workshops where the frames are to be built are prescribed by a Court of Arbitration. All riveting is done by boilermakers. Welders are recruited only from the ranks of first-class tradesmen (fitters or mechanics, and boilermakers) and are paid a special allowance over the rate for such tradesmen. Wage rates are as follows:

Fitters, turners, first-class machine operators, and boilermakers	28.625 pence	($0.476)	per hr.
Welders (electric or gas)	30.25 pence	($0.500)	per hr.
Markers-off	32.375 pence	($0.538)	per hr.
Tradesmen's helpers	22.897 pence	($0.381)	per hr.

Steel castings are purchased under contract at the following rates:

2 lbs. and under	£4. 8.8. per cwt.	($15.79 per 100 lbs.)
Over 2 lbs. up to 14 lbs.	£2.17.0. per cwt.	($10.15 per 100 lbs.)
Over 14 lbs. up to 112 lbs.	£2. 7.6. per cwt.	($ 9.35 per 100 lbs.)
Over 112 lbs.	£2. 5.7. per cwt.	($ 8.12 per 100 lbs.)

Iron castings are made in the railway workshops.

Rivets are purchased at £1.3.0. per cwt. ($4.10 per 100 lbs.)

Steel plates and rolled sections are purchased under contract at an overall rate of 14s.0d. per cwt. ($2.49 per 100 lbs.)

Electrodes are purchased at a rate per 100 feet which works out to 14.37 pence ($0.239) per pound for ¼" electrodes.

Electric current is purchased from an associated power house at 0.85 pence ($0.014) per K.W.H.

Overhead charges in the railway workshops on work for the rolling stock branch are reckoned at 37.5 per cent of labour costs.

These factual data have been used throughout in preparing estimates for this paper. The method of estimating is set out in detail and it is submitted that sufficient information is given to enable the estimates to be accepted as substantiated or to be checked by persons versed in the art.

Cost of Welding.—The method given in "Procedure Handbook of Arc Welding Design and Practice," published by The Lincoln Electric Company, is followed for estimating the cost of welding. All welds in the design are fillet welds. Details of the estimated cost of welding are as under:

Labour ....30.25 pence ($0.50) per hour
Power .... 0.85 pence ($0.014) per K.W.H
Electrodes ....14.37 pence ($0.239) per lb.

Efficiency of machines assumed 50 per cent average throughout.

Cost for continuous ⅜" fillet weld:

Labour:	$\frac{30.25}{11}$	= 2.74 pence	($0.0456)
Power:	$\frac{190 \times 30 \times 0.85}{0.5 \times 11 \times 1000}$	= 0.881 pence	($0.0146)
Electrodes:	0.6 x 14.37	= 8.662 pence	($0.1433)
Time for peening weld about equal to time for welding		= 2.74 pence	($0.0456)
Overhead		= 2.093 pence	($0.0342)
Total cost		17.076 pence	($0.2833) per foot

The cost of intermittent welds, per foot of actual weld, will be higher owing to time apparently lost in moving from one length of weld to the next though the cost per foot of joint is very drastically reduced. In this design intermittent welds are employed almost without exception and in the estimates submitted allowance is made for the apparently lost time, for operator fatigue, and for re-setting the work where necessary or advisable.

Machinery Support, Fig. 3.—This drawing shows a steel casting to be replaced by a welded construction. There are two of these castings, one right hand and one left hand. In estimating costs for these and other castings, close comparison has been made with castings of similar size and complexity actually passed through the same work-

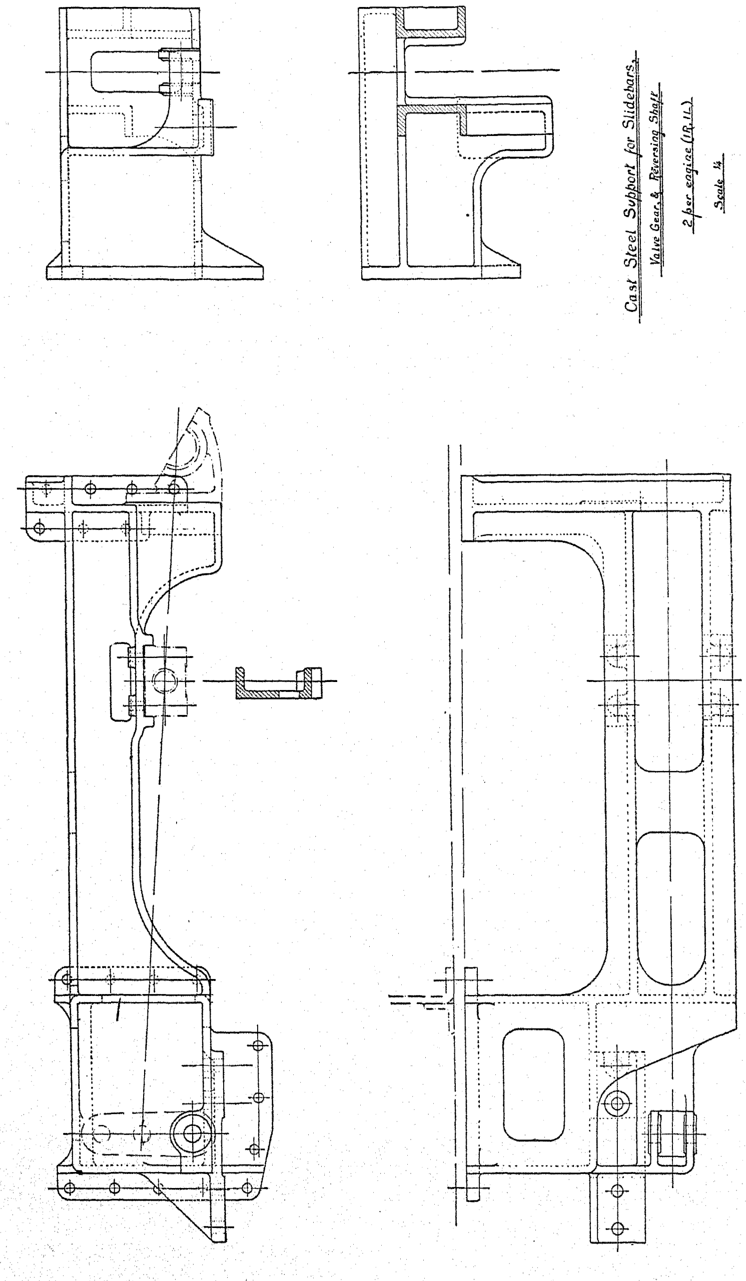

Fig. 3. Machinery support in cast steel.

shops. To debit the cost of patterns against one frame would be wrong and in all cases cost of patterns is spread over the ten engines it is proposed to build. Costs are estimated as follows:

Patterns. Two required, one right hand, one left hand.

Labour	£45. 0. 0.	($179.55)
Overhead 37.5%	16.17. 6.	($ 67.33)
Material	10.10. 0.	($ 41.90)
	£72. 7. 6.	($288.78)

Cost of patterns spread over ten engines:

Cost per engine	£7. 4. 9.	($28.88)

Finished weight of one casting	938 lbs.
allowance for machining	186 lbs.
Rough Weight	1,124 lbs.

Cost of casting: $\frac{1124 \times 45/7}{112}$		=	£22.18. 0.	($91.37)
Marking-off	4 hrs. @ 32.375d.	($0.538) =	10. 9½	($ 2.15)
Machining	13 hrs. @ 28.625d.	($0.476) =	£ 1.11. 0.	($ 6.19)
Marking-off for drilling	2 hrs. @ 32.375d.	($0.538) =	5. 5.	($ 1.08)
Drill, reamer, and face ..	4 hrs. @ 28.625d.	($0.476) =	9. 6½	($ 1.90)
Total labour per casting			£ 2.16. 9.	($11.32)
Overhead 37.5 per cent			1. 1. 3.	($ 4.24)
Total			£ 3.18. 0.	($15.56)

Total cost per engine.

Patterns	£ 7. 4. 9.	($ 28.88)
Two castings	45.16. 0.	($182.74)
Machining etc.	7.16. 0.	($31.12)
	£60.16. 9.	($242.74)

Welded Machinery Support, Fig. 4.—Owing to the need for maintaining positions determined by exterior factors and for keeping the same clearances, the welded construction follows very closely the lines of the steel casting it replaces. The channels used are the standard section used for wagon (freight car) under-frames. In this case, the bill of material is set out in detail to illustrate the method employed in estimating. Though a similar procedure has been followed in all cases, details have been omitted to avoid burdening a paper already too long. If the number of these weldings required was larger, considera-

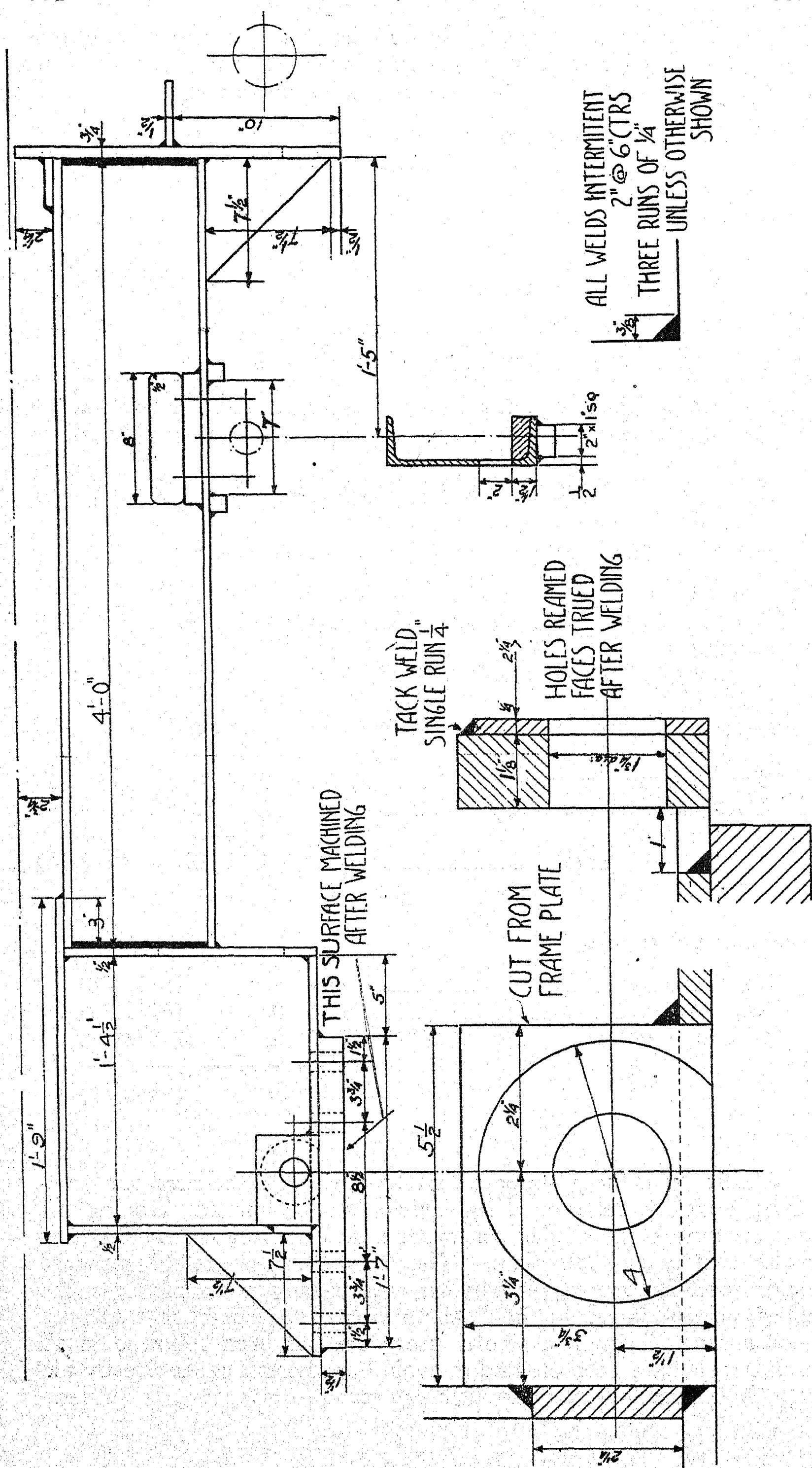

Fig. 4. Machinery support in welded construction. See additional details, pages 173b and 173c.

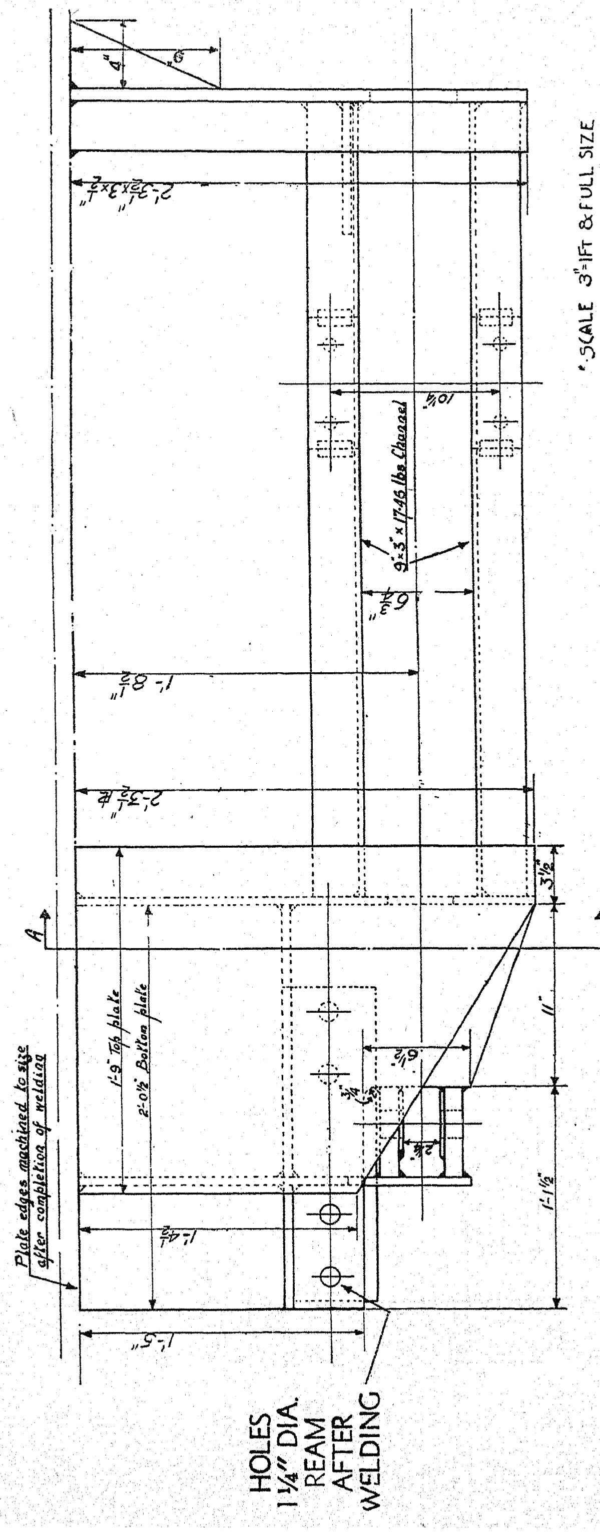

Fig. 4. Further details of welded machinery support. See also pages 173a and 173c.

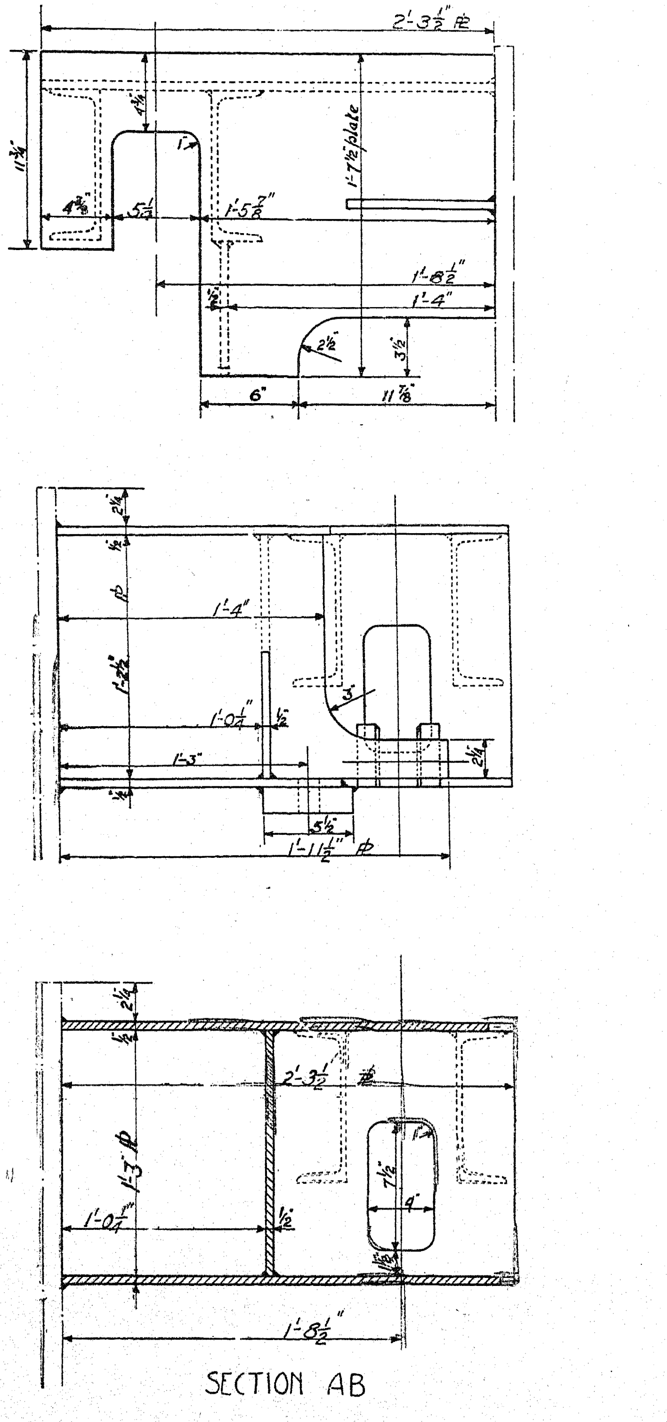

Fig. 4. Further details of welded machinery support. See also pages 173a and 173b.

tion could be given to the use of jigs. There is nothing in the job, however, which cannot conveniently be done by means of the ordinary damping methods used in railway workshops and it is considered unnecessary to load the welded design with the cost of nonessential jigs. To eliminate the effects of any distortion which may take place and to ensure accuracy of centers, etc., the structure is machined after welding is completed. This also avoids the need for great accuracy in initial cutting of plates. The amount of machining is much less than for a casting and there is not any sand-filled skin to damage tools. Costs are estimated as follows:

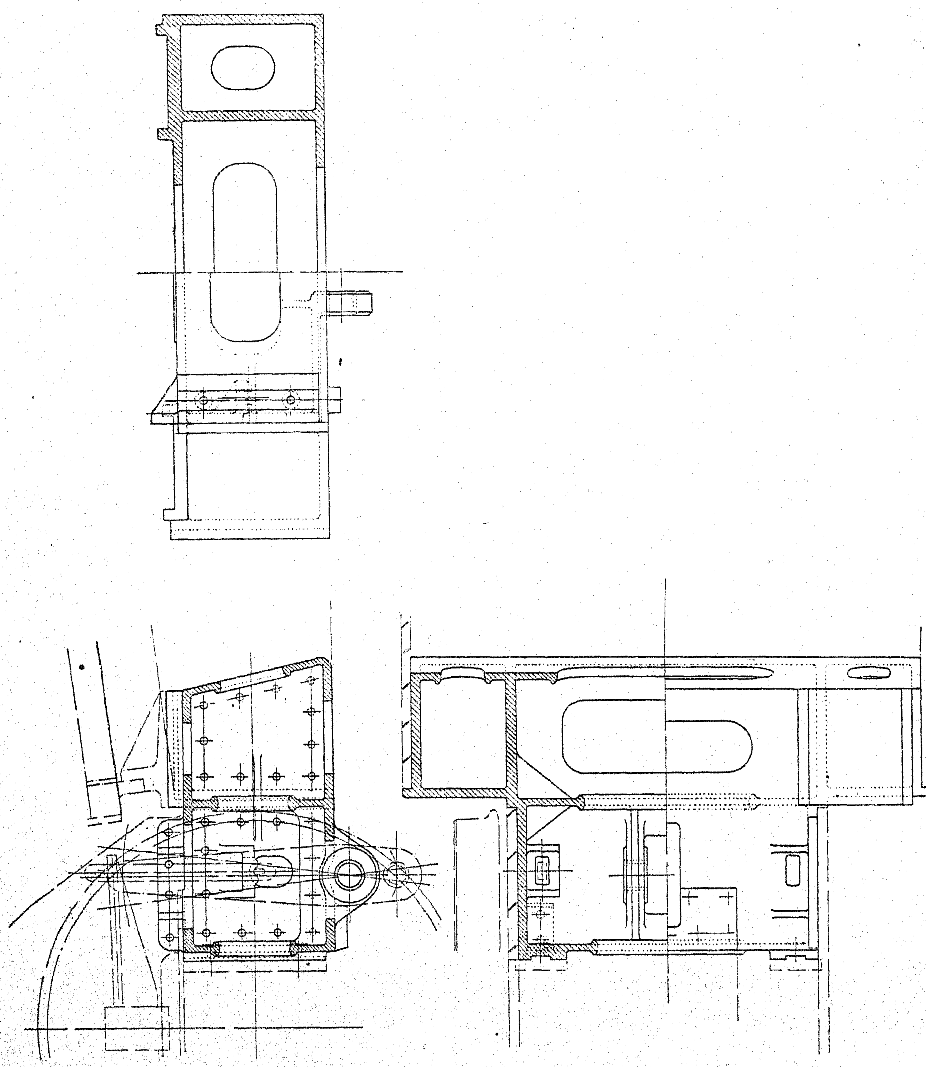

Fig. 5. Steel casting joining main and rear frames in rivetted construction.

Bill of materials for ten sets of two:

5	plates	9′6″ x 1′9″ x ½″			1,695 lbs.
5	plates	9′6″ x 2′0½″ x ½″			1,975 lbs.
5	plates	6′8″ x 1′2½″ x ½″			821 lbs.
5	plates	9′6″ x 1′3″ x ½″			1,211 lbs.
5	plates	9′6″ x 1′7½″ x ¾″			2,360 lbs.
5	plates	5′8″ x 1′2½″ x ½″			695 lbs.
1	flat	6′8″ x 7½″ x ½″			85 lbs.
1	flat	8′0″ x 4″ x ½″			55 lbs.
4	flat	8′0″ x 5½″ x 1⅝″			972 lbs.
2	flat	7′0″ x 2¾″ x 1¼″			164 lbs.
5	flat	9′6″ x 3″ x ½″			243 lbs.
1	bar	7′6″ x 1″ x 1″			26 lbs.
10	channels	16′2″ x 9″ x 3″	x 17.46 lbs		2,800 lbs.
					13,102 lbs.

Cost of material for ten sets: $\frac{13102 \times 14/—}{112}$ = £81.17. 9.

Cost per engine £8. 3. 9. ($32.67)

Finished Weight: 557 lbs. each.

Cost of fabrication for one:

Marking-off plates, etc.,	4 hrs. @ 32.375 pence ($0.538)	10. 9.5	($ 2.15)
Cutting plates etc.	4 hrs. @ 28.625 pence ($0.476)	9. 6.5	($ 1.90)
Setting up, allowance for altering position, operator, fatigue, etc.	10 hrs. @ 30.25 pence ($0.50)	£1. 5. 2.5	($ 5.03)
Marking-off for drilling and final machining	2 hrs. @ 32.375 pence ($0.538)	5. 5.	($ 1.08)
Machining and drilling	7 hrs. @ 28.625 pence ($0.476)	16. 8.	($ 3.33)
Total labour excluding welding		3. 7. 7.5	($13.49)
Overhead 37.5 per cent		1. 5. 6.	($ 5.09)
		£4.13. 1.5	($18.58)
Welding equivalent to 12′4″ continuous fillet 12 33 x 17.076 pence ($0.2833)		17. 6.5	($ 3.50)
Total		£5.10. 8.	($22.08)

Fabrication cost per engine	£11. 1. 4.	($44.16)
Material	8. 3. 9.	($32.67)
Total cost per engine	£19. 5. 1.	($76.83)

Comparison for Machinery Support, Figs. 3 and 4

	Weights per engine	Costs per engine	
Fig. 3: Cast steel	1,876 lbs.	£60.16. 9.	($242.74)
Fig. 4: Welded	1,114 lbs.	£19. 5. 1.	($ 76.83)
Saving, by arc welding	762 lbs.	£41.11. 8.	($165.91)
	= 40.6%		= 68.3%

Junction of Frames, Fig. 5.—This casting has been lightened as far as seems advisable and combines a number of functions. Costs are estimated as follows:

Finished weight	1,911 lbs.
Allowance for machining	196 lbs.
Rough	2,107 lbs.

Cost: £42.17. 6. each ($171.07)

Pattern:		
Labour	£22. 0. 0.	($ 87.78)
Material	7.15. 0.	($ 30.92)
Overhead 37½%	8. 5 0.	($ 32.92)
	£38. 0. 0.	($151.62)

Spread pattern cost over ten engines:

Cost each: £ 3.16. 0. ($15.16)

Marking-off	£ 1. 1. 7.	($ 4.31)
Machining	1.18. 3.	($ 7.63)
Marking-off	5. 5.	($ 1.08)
Drilling	9. 7.	($ 1.91)
	£ 3.14.10.	($ 14.93)
Overhead 37½%	1. 8. 1.	($ 5.60)
	£5. 2.11.	($ 20.53)

Total cost per engine:		
Pattern	£ 3.16. 0.	($ 15.16)
Casting	42.17. 6.	($171.07)
Machining	5. 2.11.	($ 20.53)
	£51.16. 5.	($206.76)

Junction of Frames, Fig. 6.—This drawing shows weldings designed to take the place of the steel casting shown in Fig. 5 and affords an example of welded design which does not follow the lines of the casting. Two entirely separate weldings are shown. One serves as axlebox guide (or pedestal) for the trailing coupled axle, main brake lever pivot and spring link bracket. The construction of the axlebox

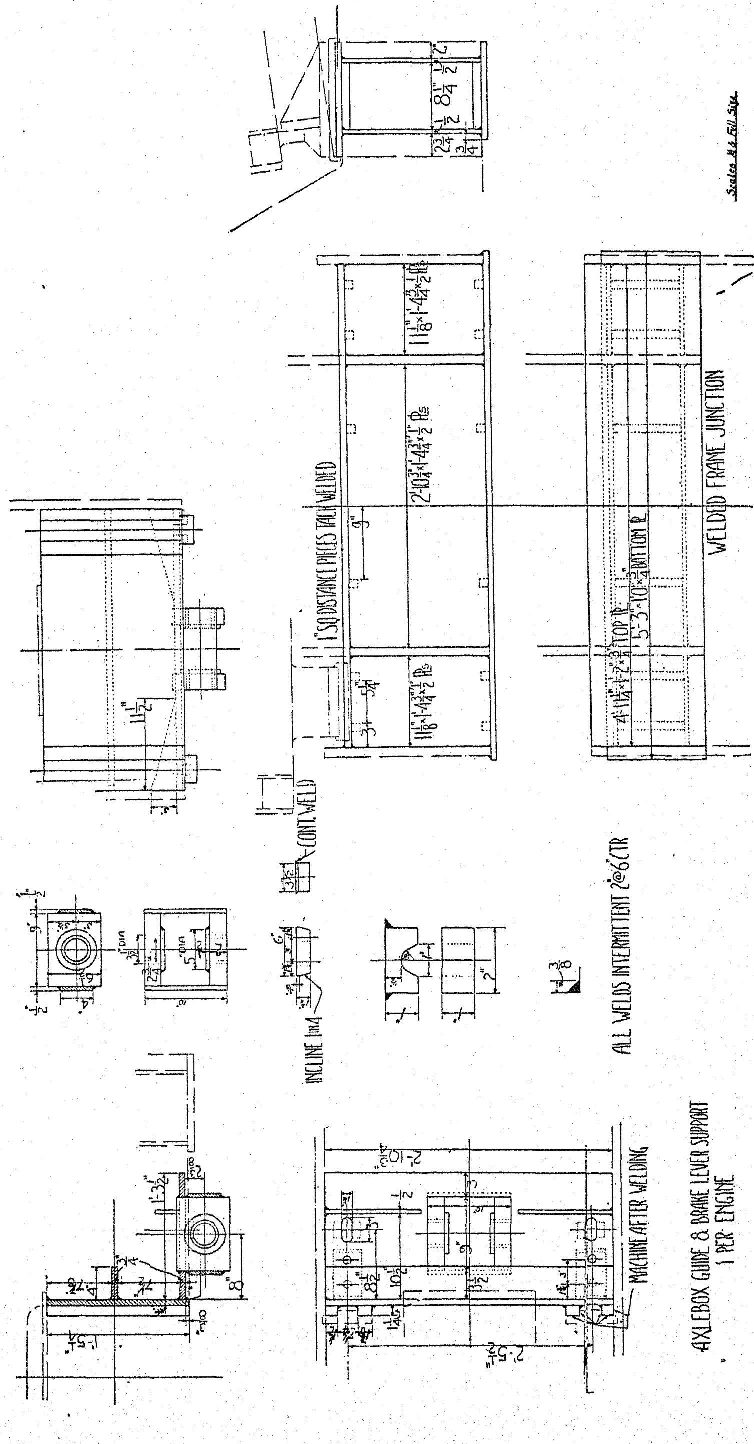

Fig. 6. Junction of main and rear frames in welded construction.

guide portion is clear from the drawing. Slippers to take wear are shown chain dotted and are common to both riveted and welded frames. To locate these slippers and provide a true face, bars are welded to the plate and machined after all welding is completed. The plates are machined on the edges at the same time as it is essential that the distance between frames be exact. For the brake lever fulcrum, two pieces of bar 2″ thick are each faced with a washer of ½″ plate lightly welded in place. The two bars are then joined with 4″ x ½″ flats and this assembly is then bored and bushed ensuring true bearings. The completed fulcrum is welded to the plate structure. There is no bending stress to be considered and this simple construction is all that is required. In conformity with practice established on this railway, cotters are used in place of pins for the spring gear, having proved much more serviceable. Simply shaped pieces of bar welded to the plate structure serve as pivots for these cotters. To take the hornstays, (or pedestal binders), shaped pieces of bar are welded to the plate. In all, sixteen of these shaped pieces are required and all would be machined at the same time. A proportion of this cost has been allowed for each welded assembly affected.

A very simple structure serves to join the main and rear frame plates, but is not a separate assembly although to allow proper comparison with the steel casting, the full cost of welding is shown in the estimate. The top horizontal plate is machined to space the rear frames correctly, the main frames being already spaced by other members. Assembly of this structure is part of the general assembly of the frames and will be dealt with later. It should be noted however, that distance pieces are lightly welded to both horizontal plates making the placing of the vertical plates a very simple matter.

Costs for the whole of the work shown on this sheet are estimated as follows:

Marking-off plates, etc.	8. 1.	($ 1.61)
Cutting plates, etc.	4.11.	($ 0.98)
Set up for welding, etc.	£ 1. 0. 2.	($ 4.02)
Marking-off	8. 1.	($ 1.61)
Machining and Drilling	14. 4.	($ 2.86)
	£ 2.15. 7.	($11.08)
Overhead 37½%	1. 2. 1.	($ 4.41)
	£ 3.17. 8.	($15.49)
Welding equal to 26 ft. continuous seam 26x17.076	1.18. 8.	($ 7.71)
	£5.16. 4.	($23.20)
Material	6.10. 2.	($25.97)
	£12. 6. 6.	($49.17)

Excluding the welding of the junction plates which is taken into account as an assembly cost, the total cost is:

£11. 4. 2. ($44.72)

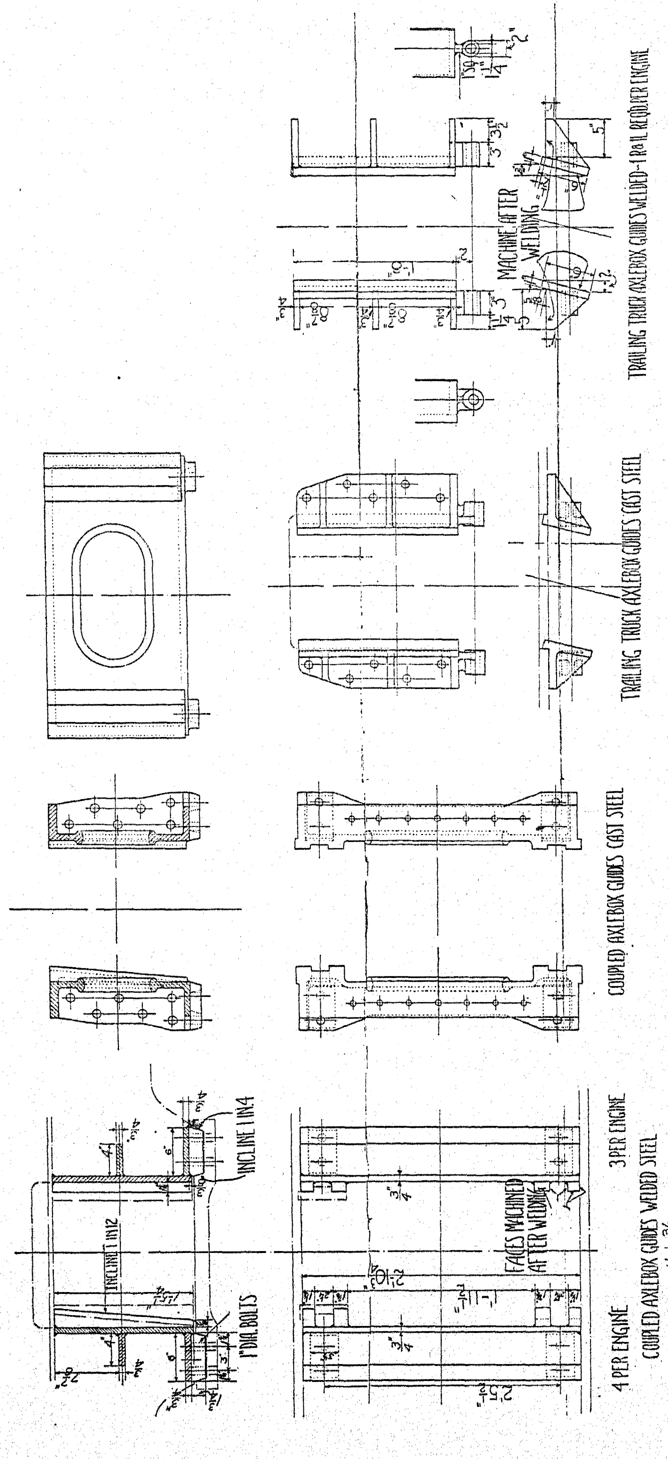

Fig. 7. Coupled axle box guides, (pedestals), in cast steel with arc welded counterparts.

Comparison for Junction Structures, Figs. 5 and 6.

	Weights per engine	Costs per engine	
Fig. 5: Cast steel	**1,911 lbs.**	**£51.16. 5.**	**($206.70)**
Fig. 6: Welded	**856 lbs.**	**12. 6. 6.**	**(49.17)**
Saving by arc welding	**1,055 lbs.**	**£39. 9.11.**	**($157.53)**
	= 55.2%		= 76.2%

Axlebox Guides, (or Pedestals), Fig. 7.—This drawing shows the original designs of cast steel guides adjacent to their welded counterparts enabling ready comparison. The cast steel guides are secured to the frame plates by fitted bolts. In addition the guides for the coupled wheel axleboxes are riveted to the main horizontal stay. Costs for the cast steel coupled wheel guides are estimated as follows:

Front guides.

Finished weight each	279 lbs.
Allowance for machining	71 lbs.
Rough weight	350 lbs.

Cost per casting:	£7. 2. 5.	($28.41)
Cost of castings (4 per engine)	£28. 9. 8.	($113.64)

Pattern.

Labour:	£5.10. 0.	($21.95)
Overhead 37.5%	2. 1. 3.	($ 8.23)
Materials:	14. 0.	($ 2.79)
	£8. 5. 3.	($32.97)

Cost of patterns spread over ten engines.

Cost per engine:	16s.3d	($ 3.30)
Marking-off	8. 1.	($ 1.61)
Machining	£1. 8. 8.	($ 5.72)
Marking-off	5. 5.	($ 1.08)
Drilling	4. 8.	($ 0.93)
	£2. 6.10.	($ 9.34)
Overhead 37.5%	17. 7.	($ 3.51)
Cost each	£3. 4. 5.	($12.85)

Cost per engine:

Pattern	16. 3.	($ 3.30)
Castings	£28. 9. 8.	($113.64)
Machining	£12.17. 8.	($ 51.40)
	£42. 3. 7.	($168.34)

The welded construction is simpler in form and is clearly shown. An extended description seems unnecessary. Machining is done after all welding is completed, thus ensuring accuracy. Costs are estimated as follows:

Marking-off plates, etc.	5. 5.	($ 1.08)
Cutting plates, etc.	7. 1.	($ 1.41)
Setting up for welding, etc.	10. 1.	($ 2.01)
Marking-off for final machining	8. 1.	($ 1.61)
Machining	£1. 8. 8.	($ 5.72)
	£2.19. 4.	($11.83)
Overhead 37.5%	£1. 2. 3.	($ 4.44)
	£4. 1. 7.	($16.27)
Welding equivalent to 8′9″ continuous fillet	12. 6.	($ 2.49)
	£4.14. 1.	($18.76)
Material	1. 8. 0.	($ 5.59)
Cost each	£6. 2. 1.	($24.35)
Cost per engine	£24. 8. 4.	($97.42)

Comparison for front coupled guides (4 per engine)

	Weights per engine	Costs per engine	
Cast steel	**1,116 lbs.**	**£42. 3. 7.**	**($168.34)**
Welded	**1,100 lbs.**	**24. 8. 4.**	**(97.42)**
Saving by arc welding	**16 lbs.**	**£17.15. 3.**	**($ 70.92) = 42%**

Construction of the rear guides for coupled wheels is very similar and it seems sufficient to show total costs as follows:

Comparison for rear coupled guides (3 per engine)

	Weights per engine	Costs per engine	
Cast steel	**870 lbs.**	**£32. 9. 0.**	**($129.48)**
Welded	**792 lbs.**	**18. 2. 9.**	**(72.37)**
Saved by arc welding	**78 lbs. = 9%**	**£14. 6. 3.**	**($ 57.11) = 44%**

The form of the cast steel guides for the trailing truck axleboxes is sufficiently clear from the drawing. In this case a separate pattern is required for each of the four guides. Taking front and hind separately, costs are estimated as follows:

Front guides—cast steel.

Finished weight each	71 lbs.
Allowance for machining	28 lbs.
Rough weight	99 lbs.

Cost each casting:	£2. 2. 0.	($ 8.38)
Cost per engine:	£4. 4. 0.	($16.76)
Patterns (2).		
Labour	£4. 0. 0.	($15.96)
Overhead 37.5%	1.10. 0.	($ 5.99)
Material	8. 6.	($ 1.70)
	£5.18. 6.	($23.65)

Cost of patterns spread over ten engines:

Cost per engine: 11s.10d. ($2.36)

Marking-off	2. 8.	($ 0.53)
Machining	4. 9.	($ 0.95)
Marking-off	8.	($ 0.13)
Drilling	1. 2.	($ 0.23)
	9. 3.	($ 1.84)
Overhead 37.5%	3. 6.	($ 0.70)
Cost each	12. 9.	($ 2.54)
Cost per engine	£1. 5. 6.	($ 5.08)
Total cost per engine.		
Patterns	11.10.	($ 2.36)
Castings	£4. 4. 0.	($16.76)
Machining	£1. 5. 6.	($ 5.08)
	£6. 1. 4.	($24.20)

The welded guide consists simply of a plate with gussets welded on and pieces of bar to take the hornclip or pedestal binder. The gussets serve as an excellent means of attachment to the frame. Gussets and plate are left full and machined after welding is completed. Costs are estimated as follows:

Marking-off plates, etc.	8.	($ 0.13)
Setting up, etc.	1. 3.	($ 0.25)
Marking-off	8.	($ 0.13)
Machining	2. 5.	($ 0.48)
Drilling	8.	($ 0.13)
	5. 8.	($ 1.13)
Overhead 37.5%	2. 2.	($ 0.43)
	7.10.	($ 1.56)
Welding 2.5 x 17.076	3. 7.	($ 0.71)
	11. 5.	($ 2.27)
Material	9. 9.	($ 1.95)
Cost each	£1. 1. 2.	($ 4.22)
Cost per engine	£2. 2. 4.	($ 8.44)

Comparison for front guides trailing truck.

	Weights per engine	Costs per engine	
Cast steel	142 lbs.	£ 6. 1. 4.	($ 24.20)
Welded	98 lbs.	£ 2. 2. 4.	($ 8.44)
Saving by arc welding	44 lbs.	£ 3.19. 0.	($ 15.76)
	= 31%		= 65%

For the rear guides for trailing truck axleboxes the comparison is:

	Weights per engine	Costs per engine	
Cast steel	146 lbs.	£ 6. 3. 0.	($ 24.54)
Welded	104 lbs.	£ 2. 6. 4.	($ 9.24)
Saving by arc welding	42 lbs.	£ 3.16. 8.	($ 15.30)
	= 28.8%		= 62.4%

Fig. 8 and Fig. 9.—These drawings show various small brackets which must be affixed to the frame. Lengthy descriptions are not warranted as the weldings are very simple and the drawings are self explanatory. It may be noted that the weights of these members for the riveted frame are due mainly to the fact that provision must be made for bolts or rivets. Estimates of costs are given below without further comment.

Compensating beam brackets (6 per engine).

Cast steel.

Finished weight each		34 lbs.
Allowance for machining		4 lbs.
Rough weight		38 lbs.

Cost each: 16s.ld. ($ 3.21)		
Cost per engine	£4.16. 6.	($19.25)
Pattern.		
Labour:	£1.10. 0.	($ 5.99)
Overhead 37.5%	11. 3.	($ 2.22)
Material:	5. 0.	($ 1.00)
	£2. 6. 3.	($ 9.21)
Cost of pattern spread over ten engines:		
Cost per engine: 4s.8d. ($0.92)		
Marking-off	8.	($ 0.13)
Machining	1. 2.	($ 0.23)
Marking-off	8.	($ 0.13)
Drilling	7.	($ 0.12)
	3. 1.	($ 0.61)
Overhead 37.5%	1. 2.	($ 0.23)
Cost each	4. 3.	($ 0.84)
Cost per engine	£1 5. 6.	($ 5.09)

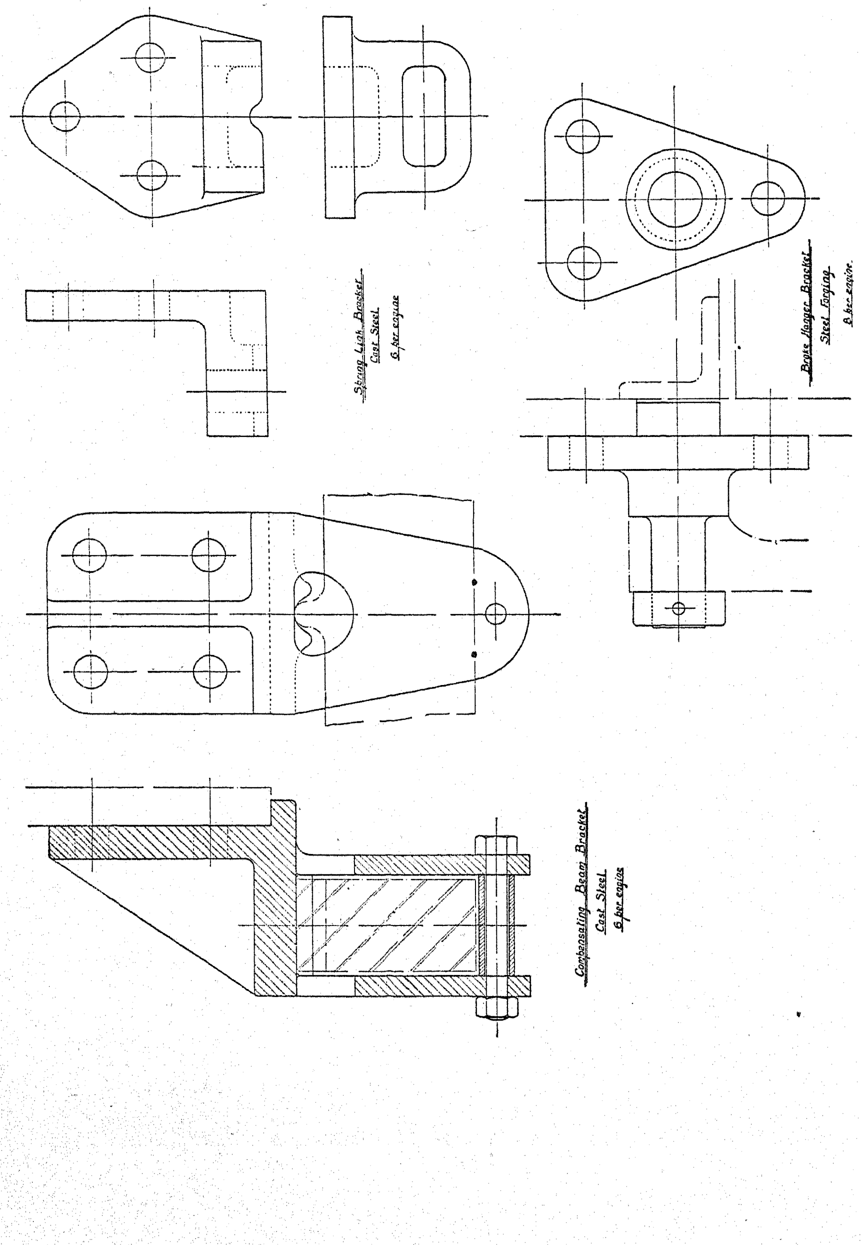

Fig. 8. Spring compensating beam brackets, spring link brackets, and brake hangar brackets for rivetted construction.

Total cost per engine.

Pattern	4. 8.	($ 0.92)
Castings	£4.16. 6.	($19.25)
Machining	£1. 5. 6.	($ 5.09)
	£6. 6. 8.	($25.26)

Welding.

Marking-off plates, etc.	8.	($ 0.13)
Cut, bend, machine bearing piece	2. 5.	($ 0.48)
Drilling	4.	($ 0.07)
Setting up	7.	($ 0.12)
	4. 0.	($ 0.80)
Overhead 37.5%	1. 6.	($ 0.30)
	5. 6.	($ 1.10)
Welding, say 1.5 x 17.076	2. 2.	($ 0.43)
Each	7. 8.	($ 1.53)
Per engine	£2. 6. 0.	($ 9.18)
Material	8.10.	($ 1.76)
Cost per engine	£2.14.10.	($10.94)

Comparison.

	Weights per engine	Costs per engine	
Cast steel	**224 lbs.**	**£ 6. 6. 8.**	**($ 25.26)**
Welded	**59 lbs.**	**£ 2.14.10.**	**($ 10.94)**
Saving by arc welding	**165 lbs.**	**£ 3.11.10.**	**($ 14.32)**
	= 73.7%		= 56.7%

Spring Link Brackets (6 per engine):

Cast Steel.

Finished weight	12 lbs.
Allowance for machining	3 lbs.
	15 lbs.

Cost each 6s.4d. ($1.26)

Cost per engine	£1.18. 0.	($ 7.58)

Pattern.

Labour	£1. 0. 0.	($ 3.99)
Overhead 37.5%	7. 6.	($ 1.50)
Material	2. 6.	($ 0.50)
	£1.10. 0.	($ 5.99)

Cost of pattern spread over ten engines = 3s.0d. ($0.60) per eng.

Marking-off	8.	($ 0.13)
Machining	1. 2.	($ 0.23)
Marking-off	4.	($ 0.07)
Drilling	4.	($ 0.07)
	2. 6.	($ 0.50)
Overhead 37.5%	1. 0.	($ 0.20)
Cost each	3. 6.	($ 0.70)
Cost per engine	£1. 1. 0.	($ 4.20)

Total cost per engine.

Pattern	3. 0.	($ 0.60)
Castings	1.18. 0.	($ 7.58)
Machining	1. 1. 0.	($ 4.20)
	£3. 2. 0.	($12.38)

Welding:

Marking-off plates	8.	($ 0.13)
Cut, bend, machine bearing pieces	1. 9.	($ 0.35)
Setting up	7.	($ 0.12)
	3. 0.	($ 0.60)
Overhead 37.5%	1. 2.	($ 0.23)
Welding, say 0.75 x 17.076	1. 1.	($ 0.22)
Cost each	5. 3.	($ 1.05)
Cost per engine	£1.11. 6.	($ 6.28)
Material	8. 9.	($ 1.74)
	£2. 0. 3.	($ 8.04)

Comparison

	Weights per engine	Costs per engine	
Cast steel	72 lbs.	£ 3. 2. 0.	($ 12.38)
Welded	39 lbs.	£ 2. 0. 3.	($ 8.04)
Saving by arc welding	33 lbs.	£ 1. 1. 9.	($ 4.34)
	= 45.9%		= 35%

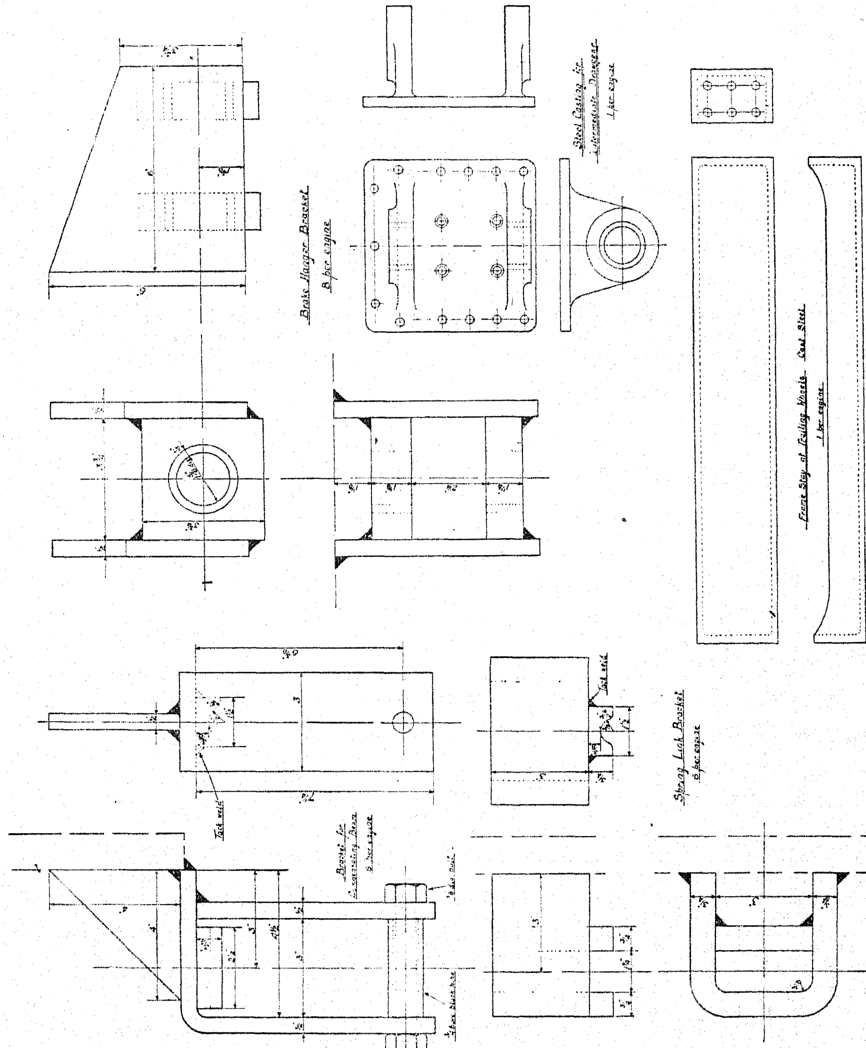

Fig. 9. Spring compensating beam brackets and spring link brackets for arc welded construction; also steel castings for intermediate drawgear and frame stay in rivetted construction.

Brake Hanger Brackets (8 per engine).

Cost of dies for stamping.

Forging die blocks	£4.10. 0.	($ 17.96)
Marking, machining, finishing	£3. 0. 0.	($ 11.97)
	£7.10. 0.	($ 29.93)
Overhead 37.5%	2.16. 3.	($ 11.22)
	£10. 6. 3.	($ 41.15)
Material	2.10. 0.	($ 9.98)
	£12.16. 3.	($ 51.13)

Cost of stamping 80 forgings.

Rough forging	£12. 4. 0.	($ 48.68)
Drop stamping	8. 8. 0.	($ 33.52)
	£20.12. 0.	($ 82.20)
Overhead 37.5%	7.14. 6.	($ 30.82)
	£28. 6. 6.	($113.02)
Material	11. 5. 0.	($ 44.89)
	£39.11. 6.	($157.91)
Add dies	12.16. 3.	($ 51.13)
Total cost of 80 forgings	£52. 7. 9.	($209.04)

Cost each: 13s.1d. ($2.61)

Machining	1.10.	($ 0.37)
Marking-off	4.	($ 0.07)
Drilling	4.	($ 0.07)
	2. 6.	($ 0.50)
Overhead 37.5%	1. 0.	($ 0.20)
	3. 6.	($ 0.70)
Forging	13. 1.	($ 2.61)
Cost each	16. 7.	($ 3.31)

Cost per engine £6.12. 8. ($26.47)

Welding.

Marking-off plates	8.	($ 0.13)
Cut plates, drill, turn bushes	2. 4.	($ 0.47)
Bush and set up	1. 3.	($ 0.25)
	4. 3.	($ 0.85)
Overhead 37.5%	1. 7.	($ 0.32)
	5.10.	($ 1.16)
Welding 2 x 17.076	2.10.	($ 0.57)
Cost each	8. 8.	($ 1.73)
Cost per engine	£3. 9. 4.	($13.83)
Material	8. 9.	($ 1.75)
	£3.18. 1.	($15.58)

Comparison

	Weights per engine	Costs per engine	
Forging	**120 lbs.**	**£ 6.12. 8.**	**($ 26.47)**
Welding	**100 lbs.**	**£ 3.18. 1.**	**($ 15.58)**
Saving by arc welding	**20 lbs.** = 16.7%	**£ 2.14. 7.**	**($ 10.89)** = 41%

Frame Stay at Trailing Truck Wheels, Fig. 9.—This casting and its welded counterpart (shown in Fig. 2) are so simple that description is unnecessary. Costs are estimated in the same manner to give the following comparison:

	Weights per engine	Costs per engine	
Cast steel	**196 lbs.**	**£ 4.19.11.**	**($ 19.93)**
Welding	**170 lbs.**	**£ 1.19. 2.**	**($ 7.81)**
Saving by arc welding	**26 lbs.** = 13.25%	**£ 3. 0. 9.**	**($ 12.12)** = 60.8%

Hind Drag Box.—In the riveted design, the tractive effort of the engine is transmitted by means of a plate structure and a steel casting which are entirely replaced by a plate structure in the welded design. An additional frame stay is provided behind the trailing truck axle in the welded design and for costing is included with the drag box. The buffer beams (or planks) at both ends of the riveted frame and the front end of the welded frame are costed separately. Costs for the drag boxes are estimated as follows:

Rivetted Frame.

$\frac{1}{10}$ cost of Pattern (Sheet 9)	11. 5.	($ 2.28)
Casting	£20.11. 9.	($ 82.14)
Machining and overhead	2. 4. 3.	($ 8.83)
	£23. 7. 5.	($ 93.25)

Cutting plates	5. 0.	($ 1.00)
Flanging	£1. 2. 8.	($ 4.52)
Machining	2. 4.	($ 0.47)
Marking-off	8. 1.	($ 1.61)
Drilling	9. 7.	($ 1.91)
Rivetting	11.11.	($ 2.38)
	£2.19. 7.	($ 11.89)
Overhead 37.5%	1. 2. 4.	($ 4.45)
	£4. 1.11.	($ 16.34)
Material	5.11. 5.	($ 22.23)
	£9.13. 4	($ 38.57)
Steel casting	£23. 7. 5.	($ 93.25)
Total cost per engine	£33. 0. 9.	($131.82)

Welded Frame.

Cutting plates	12. 6.	($ 2.49)
Edge planing	2. 8.	($ 0.53)
Setting up	17. 8.	($ 3.52)
Welding	£2. 2. 2.	($ 8.41)
Boring & facing	1. 1. 0.	($ 4.19)
Machining to length	14. 4.	($ 2.86)
	£5.10. 4.	($22.00)
Overhead 37.5%	2. 1. 5.	($ 8.26)
	£7.11. 9.	($30.26)
Material	7. 6. 4.	($29.20)
	£14.18. 1.	($59.46)

Comparison.

	Weights per engine	Costs per engine	
Rivetted frame	**1,862 lbs.**	**£33. 0. 9.**	**($131.82)**
Welded	**879 lbs.**	**£14.18. 1.**	**($ 59.46)**
Saving	**983 lbs.**	**£18. 2. 8.**	**($ 72.36)**
	= 52.7%		= 54.8%

Frame Stay and Bogie Centre, Fig. 10.

1/10 cost of pattern	13.10.	($ 2.76)
Steel casting	£22.19. 6	($ 91.67)
Machining and overhead	2. 3. 8.	($ 8.71)
Cost per engine	£25.17. 6.	($103.24)

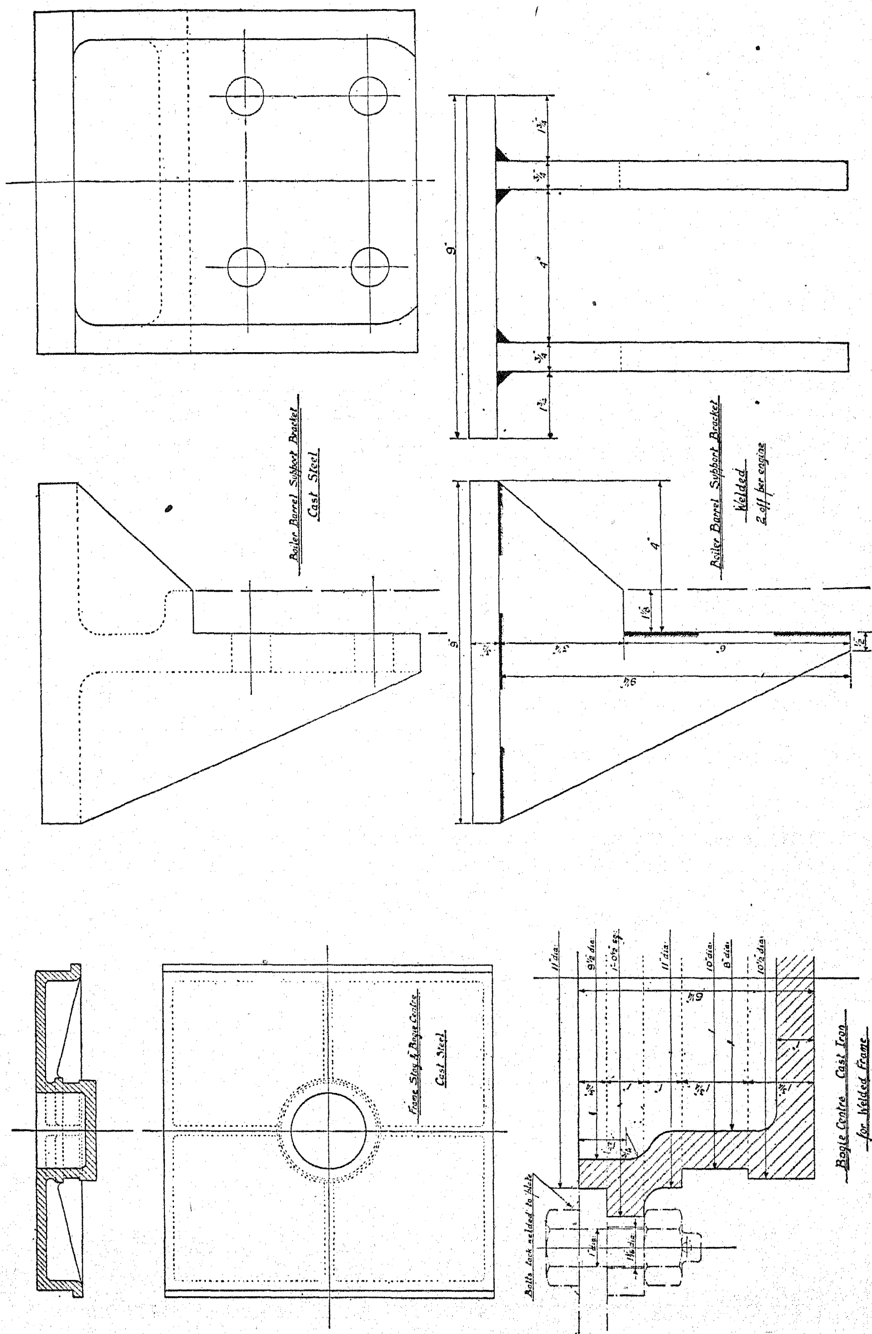

Fig. 10. Steel castings for frame stay and boiler barrel support brackets in rivetted construction; also boiler barrel support brackets in welded construction.

Cast Iron Centre.

1/10 cost of pattern	4. 8.	($ 0.92)
Casting	11. 6.	($ 2.29)
Machining and overhead	16. 1.	($ 3.21)
Cost each	£1.12. 3.	($ 6.43)
Marking-off plates	2. 8.	($ 0.53)
Cutting plates	3. 7.	($ 0.71)
Drilling	4.10.	($ 0.96)
	11. 1.	($ 2.20)
Overhead 37.5%	4. 2.	($ 0.83)
	15. 3.	($ 3.03)
Material	£1.18. 3.	($ 7.63)
	£2.13. 6.	($ 10.66)
*Welding gussets	6. 6.	($ 1.30)
	£3. 0. 0.	($ 11.97)
Add casting	1.12. 3.	($ 6.43)
Total cost per engine	£4.12. 3.	($ 18.40)

*included for comparison, actually part of assembly, cost without welding £4. 5. 9. ($17.11).

Comparison.

	Weights per engine	Costs per engine	
Cast steel	**1,076 lbs.**	**£25.17. 6.**	**($103.24)**
Welding and cast iron	**308 lbs.**	**£ 4.12. 3.**	**($ 18.40)**
Saving by arc welding	**768 lbs. = 71.3%**	**£21. 5. 3.**	**($ 84.84) = 85.9%**

Boiler Barrel Support Bracket, Fig. 10.—Here again simplicity is evident and full description is not warranted. Costs are estimated as follows:

1/10 cost of patterns	3. 0.	($ 0.60)
Two steel castings	£3. 5. 4.	($13.03)
Machining & overhead	12. 0.	($ 2.40)
Cost per engine	£4. 0. 4.	($16.03)
Marking-off plates	1. 4.	($ 0.27)
Machining	2. 5.	($ 0.48)
Setting up	2. 6.	($ 0.50)
	6. 3.	($ 1.25)
Overhead 37.5%	2. 4.	($ 0.46)
	8. 7.	($ 1.71)
Welding 2 x 17.076	2.10.	($ 0.57)
	11. 5.	($ 2.28)
Material	13.11.	($ 2.77)
Cost each	£1. 5. 4.	($ 5.05)
Cost per engine	£2.10. 8.	($10.10)

Comparison.

	Weight per engine	Cost per engine	
Cast steel	**124 lbs.**	**£ 4. 0. 4.**	**($ 16.03)**
Welded	**55 lbs.**	**£ 2.10. 8.**	**($ 10.10)**
Saving by arc welding	**69 lbs.**	**£ 1. 9. 8.**	**($ 5.93)**
	= 55.5%		= 37%

This completes references to detail drawings. Comparisons of plate members in the two designs follow, but it is thought unnecessary to give full details of the estimates. Much of the weight saving is due to the elimination of angles. In a riveted structure it is necessary to provide space for reasonable rivet pitching, and this sometimes occasions members larger than otherwise needed. Reduction in material, elimination of drilling and riveting of angles to plates contribute the bulk of the monetary savings.

Buffer Beams.

Weights per engine		Costs per engine			
Rivetted (includes angles)	1,759 lbs.	Material	£10.19.11 ($43.87)		
		Labour & overhead	£ 1.14. 3 ($ 6.83)		
			Total	£12.14. 2	($50.70)
Welded	600 lbs.	Material	£ 3.15. 0 ($14.96)		
		Labour & overhead	16. 2 ($ 3.19)		
			Total	£ 4.11. 2	($18.15)
Saving by arc welding	**1,159 lbs.**			**£ 9. 3. 0**	**($32.55)**
	= 65.8%			= 64.2%	

Stays Behind Buffer Beams.

Weights per engine		Costs per engine			
Rivetted (includes angles)	684 lbs.	Material	£4.13. 0. ($18.55)		
		Labour & overhead	£2. 4. 4. ($ 8.55)		
			Total	£6.17. 4.	($27.40)

Welded	388 lbs.	Material £2.10. 9. ($10.12)		
		Labour & overhead .... 6.10. ($ 1.36)		
			Total....................	£2.17. 7. ($11.48)
Saving by arc welding	**296 lbs.**			**£3.19. 9. ($15.92)**
	= 43.3%			= 58%

Vertical Stays at Cylinders.

Weights per engine		Costs per engine		
Rivetted	502 lbs.	Material £4. 2. 0. ($16.36)		
		Labour & overhead £3. 7. 0. ($13.37)		
			Total....................	£7. 9. 0. ($29.73)
Welded	416 lbs.	Material £3. 9.10. ($13.93)		
		Labour & overhead ....£ 8. 7. ($ 1.71)		
			Total....................	£3.18. 5. ($15.64)
Saving by arc welding	**86 lbs.**			**£3.10. 7. ($14.09)**
	= 17%			= 47.4%

Main Horizontal Stay.

Weights per engine		Costs per engine		
Rivetted (includes angles).	1,307 lbs.	Material £9.12. 0. ($38.30)		
		Labour & overhead £6. 7. 2. ($25.37)		
			Total....................	£15.19. 2. ($63.67)
Welded	1,040 lbs.	Material £7.15. 6. ($31.02)		
		Labour & overhead ....£1.18. 3. ($ 7.64)		
			Total....................	£ 9.13. 9. ($38.66)
Saving by arc welding	**267 lbs.**			**£ 6. 5. 5. ($25.01)**
	= 20.4%			= 39.3%

Vertical Stays Between Wheels.—In the welded design, the thickness of the stays is reduced from ¾″ to ½″ but additional members are provided, giving a considerable net gain in strength.

Weights per engine		Costs per engine		
Rivetted (includes angles).	993 lbs.	Material	£6. 2. 5.	($24.34)
		Labour & overhead	£9.16.11.	($41.28)
		Total	£15.18. 4.	($65.62)
Welded	520 lbs.	Material	£3.12. 3	($14.41)
		Labour & overhead	17.11.	($ 3.57)
		Total	£ 4.10. 2.	($17.98)
Saving by arc welding	473 lbs. = 47.5%		£11. 8. 2.	($47.64) = 72.6%

Thickening Plates Over Trailing Truck Axle.—The only difference is in the method of attachment. Marking off and drilling give the difference in costs:

	Weights per engine	Costs per engine	
Rivetted	324 lbs.	£2.15.10.	($11.14)
Welded	324 lbs.	£2. 7. 6.	($ 9.48)
Saving by arc welding	Nil	8. 4.	($ 1.76) = 15.8%

Main and Rear Frame Plates.—The practice in these workshops is to mark off one frame plate only which is machined to profile and drilled; then used as a template for the remaining plates. So far as profile is concerned, plates for the two methods of construction are identical save at the junction of main and rear frames. Costs are estimated as follows, the times for marking off, etc., being based upon comparisons with other frames of nearly equal size built in the same shops.

Main Plates for Riveted Frame.

Marking-off 52 man hrs. @ 32.375 pence	£7. 0. 4.	($28.00)
Overhead 37.5%	2.12. 8.	($10.50)
	£9.13. 0.	($38.50)

This cost spread over ten engines. Cost per engine **19s.4d. ($3.86)**

Hand cutting by torch—operator guides torch ¼″ from line.

Cutting:	18 man hours per plate 1⅛″ thick.
Scribing from template	1 man hour
	19 man hours @ 30.25 pence £2. 7.11. ($8.56)

Labour per engine	£4.15.10.	($19.12)
Overhead 37.5%	1.15.11.	($ 7.16)
Cost per engine	£6.11. 9.	($26.28)

Three plates are profile milled together:

Setting up and bolting down template	8 man hours
Milling	32.25 man hours
	40.25 man hours

40.25 @ 28.625 pence	£4.16. 0.	($19.15)
Overhead 37.5%	£1.16. 0.	($ 7.18)
	£6.12.0.	($26.33)
Cost per engine = ⅔ x £6.12. 0.	£4. 8. 0.	($17.56)
Add one tenth cost of milling template	13. 3.	($ 2.64)
Cost per engine	£5. 1. 3.	($20.20)

Set up and drill in pairs:

26 man hours @ 28.625 pence	£6. 4. 0.	($24.74)
Overhead 37.5%	2. 6. 6.	($ 9.28)
Cost per engine	£8.10. 6.	($34.02)

Total Costs.

Material	£60.14. 6.	($242.29)
Marking-off	19. 4.	($ 3.86)
Oxy cutting	6.11. 9.	($ 26.28)
Milling	5. 1. 3.	($ 20.20)
Drilling	8.10. 6.	($ 34.02)
	£81.17. 4.	($326.65)

Main Plates for Welded Frame.

Marking-off 16 man hours @ 32.375 pence	£2. 3. 8.	($ 8.71)
Overhead 37.5%	16. 4.	($ 3.26)
	£3. 0. 0.	($11.97)

This cost spread over ten engines. Cost per engine 6s.0d. ($1.20)

Oxy cutting 20 man hours @ 30.25 pence	£2.10. 5.	($10.06)
Per engine	£5. 0.10.	($20.12)
Overhead 37.5%	2. 0. 8.	($ 8.11)
	£7. 1. 6.	($28.23)
Milling three plates 42 man hours @ 28.625 pence	£5. 0. 2.	($19.98)
Overhead 37.5%	£1.17. 7.	($ 7.50)
	£6.17. 9.	($27.48)
Cost per engine ⅔ x £6.17. 9. =	£4.11.10.	($18.32)
Add one-tenth cost milling template	13. 9.	($ 2.74)
Cost per engine	£5. 5. 7.	($21.06)
Set up and drill in pairs: 6 man hours @ 28.625 pence	14.4.	($ 2.86)

Total Costs.

Material	£63. 1. 0.	($251.57)
Marking-off	6. 0.	($ 1.20)
Oxy cutting	7. 1. 6.	($ 28.23)
Milling	5. 5. 7.	($ 21.06)
Drilling	14. 4.	($ 2.86)
	£76. 8. 5.	($304.92)

Comparison.

	Weights per engine	Costs per engine	
Rivetted	6,739 lbs.	£81.17. 4.	($326.65)
Welded	6,808 lbs.	£76. 8. 5.	($304.92)
Saving by arc welding	**69 lbs.**	**£ 5. 8. 9.**	**($ 23.73)**

Similar estimates for the rear frame plates give:

	Weights per engine	Costs per engine	
Rivetted	2,028 lbs.	£30.15. 9.	($122.84)
Welded	2,050 lbs.	£29. 5. 9.	($116.85)
Saving	**22 lbs.**	**£ 1.10. 0.**	**($ 5.99)**

The bolts and rivets of the original design are eliminated completely by adoption of welding and their costs must be credited as a saving to the new design. Though the weight saved lies only in the bolt heads, nuts and rivet heads it is appreciable.

Fitted bolts in riveted structure:

1¼″ dia. (Whitworth)	24 off 3¾″ long	
	32 off 4⅜″ long	
	12 off 4¾″ long	
	68	68
1″ dia. (Whitworth)	12 off 2⅞″ long	
	47 off 3¼″ long	
	158 off 3⅜″ long	
	8 off 3½″ long	
	10 off 3¾″ long	
	14 off 4 ″ long	
	16 off 4¼″ long	
	265	265
	Total	333

Weight of bolt heads and nuts (including portion of bolt) 500 lbs.
Costs Are:

Machining	£4. 1. 8.	($16.29)
Overhead 37.5%	1.10. 8.	($ 6.12)
Material	8.14. 0.	($34.71)
Per engine	£14. 6. 4.	($57.12)

Rivets:

⅞″ dia	12 off 3½″ long	
	24 off 3⅛″ long	
	48 off 3 ″ long	
	30 off 2⅞″ long	
	62 off 2⅜″ long	
	48 off 2¼″ long	
	224	224
¾″ dia.	10 off 2¾″ long	
	28 off 2¼″ long	
	102 off 2⅛″ long	
	68 off 2 ″ long	
	28 off 1¾″ long	
	293 off 1⅝″ long	
	529	529
	Total	753

Cost at £1. 3. 0. per cwt. ($4.10 per 100 lbs.)
£3.14. 7. ($14.87)
Weight of rivet heads—198 lbs.

Assembly.—Ordinarily rivetted frames are assembled and bolted up by a fitter, fifth-year apprentice, and helper. Wages for these three total 68.864 pence ($1.1449) per hour. Based on experience with other frames in the same shops, costs for the rivetted frame are—

Assembling, lining up, reamering holes, bolting up	£50.10. 0.	($201.50)
Rivetting	10. 9.10.	($ 41.86)
	£60.19.10.	($243.36)
Overhead 37.5%	22.17. 5.	($ 91.25)
	£83.17. 3.	($334.61)

In assembling the welded frame, no welds would be completed until all structural parts had been placed and tack welded to prevent movement. This, together with the use of intermittent welds peened as applied by operators working on both sides of the frame simultaneously, would provide ample security against distortion. Probably the method suggested and the extensive use of sub-assemblies described in this paper are more expensive than other methods which could be used. It is very necessary, however, that there be no real risk of distortion and for this reason the suggested methods are held to be fully justified. The assembly costs given below may be criticised as somewhat overestimated, but it is thought better to incur this criticism than to overestimate the savings accruing from the employment of welding and this idea has been followed throughout the paper. A fitter, welder, fifth-year apprentice, and helper would be employed on this assembly with wages totalling 99.1136 pence ($1.6478) per hour or 792.91 pence ($13.1836) per day of 8.8 hours. Costs are—

Set up coupled axlebox guides in pairs, fit horn stays (pedestal binders) (no welder) 2 days	£ 4.11.10.	($ 18.32)
Set up main plates in stools and square (no welder 1 day	£ 2. 5.11.	($ 9.16)
Place coupled axlebox guides in frames and tack weld. 2 days	£ 6.12. 2.	($ 26.37)
Place stay between frames at front buffer beam and tack weld. ½ hour	4. 2.	($ 0.83)
Place front buffer beam and tack weld. ½ hour	4. 2.	($ 0.83)
Place front buffer beam gussets and tack weld to beam and frame. ½ hour	4. 2.	($ 0.83)

Place vertical stays at cylinders and tack weld. 1 hour	8. 3.	($ 1.65)
Place horizontal stay at cylinders, tack weld to vertical stays and frame, place gussets and tack weld. 1 hour	8. 3.	($ 1.65)
Place long horizontal plate between front buffer beam and cylinder stays and tack weld. ½ hour	4. 2.	($ 0.83)
Place main horizontal stay and tack weld to cylinder stays, frames and axlebox guides. 1½ hours	12. 5.	($ 2.48)
Place vertical stays between wheels, tack weld to frames and horizontal stay, place capping plates and tack weld to frames and stays. 3 hours	£ 1. 4. 9.	($ 4.94)
Weld trailing truck axlebox guides to rear frames (included in assembly welding). Weld thickening plates to rear frame (included in assembly welding). Set up rear frames in stools, place drag box and tack weld. 1 day	£ 3. 3. 1.	($ 12.59)
Place vertical stays at trailing truck axle and tack weld. 1 hour	8. 3.	($ 1.65)
Place outside plates and gussets at rear of frame and tack weld. ½ hour	4. 2.	($ 0.83)
Place top and bottom junction plates and tack weld to main frame. 1 hour	8. 3.	($ 1.65)
Assemble rear frames to main frames and tack weld to junction plates. 3 hours	£ 1. 4. 9.	($ 4.94)
Weld top and bottom junction plates to main and rear frame plates (included in assembly welding). Place vertical junction plates and weld (included in assembly welding).		
	£22. 8. 9.	($ 89.53)
Overhead 37.5%	8. 8. 3.	($ 33.56)
	£30.17. 0.	($123.09)

Complete assembly welding 546 ft. intermittent weld = 182 ft. continuous weld plus 21 ft. continuous weld plus			
203 ft. @ 17.076 pence		£14. 8.10.	($ 57.62)
Add 50% to labour cost of welding as allowance for changing position, fatigue, etc.			
203 x 2.74 pence	£2. 6. 4.		
Overhead 37.5%	17. 5.		
	£3. 3. 9.	£ 3. 3. 9.	($ 12.72)
		£48. 9. 7.	($193.43)
Place and weld brake hanger brackets, spring link brackets, compensating beam brackets, boiler barrel support brackets, included for convenience in assembly welding.			
Place machinery supports and tack weld. 3 hours		£ 1. 4. 9.	($ 4.94)
Overhead 37.5%		9. 3.	($ 1.84)
Weld machinery supports to frames (included in assembly welding).			
Total for assembly		£50. 3. 7.	($200.21)

It is now possible to state the total cost and weight for each design. The weights given in the detailed estimates for the welded frame should be increased by 122 lbs. to allow for the welds added in assembly. Final costs and weights are—

	Cost		Weight
Rivetted	**£559.15. 0.**	**($2,233.40)**	**24,769 lbs.**
Welded	**£293.12. 2.**	**($1,171.50)**	**17,942 lbs.**
Saving by arc welding	**£266. 2.10.** = 47.5%	**($1,061.90)**	**6,827 lbs.** = 27.5%

For complete comparison, the cost and weight of hornstays (pedestal binders) which are common to both designs should be added. This does not affect the amount of saving in cost or weight but affects the percentages as follows:—

	Cost		Weight
Rivetted	**£571.15. 6.**	**($2,281.38)**	**25,257 lbs.**
Welded	**$305.12. 8.**	**($1,219.48)**	**18,430 lbs.**
Saving by arc welding	**£266. 2.10.** **= 46.5%**	**($1,061.90)**	**6,827 lbs.** **= 27%**

To those who may conceive that the size of fillet adopted in the welded design is too small and that the saving is artificially inflated, the writer would point out that the actual cost of welding is only 11.5 per cent of the total cost and that even if it be doubled throughout the monetary saving would still be 41.7 per cent, while the saving in weight would be practically unaffected.

It is not yet sufficiently appreciated that the economy of arc welding does not lie in the process itself, but in the great simplification in constructional methods which it makes possible. As previously mentioned, the change is so great that complete freshness of approach to design problems is essential.

Gross Savings to Industry by Adoption of This Design.—Where one is dealing with a product of an established industry with a known quantity of production, calculation of gross savings is a simple matter. The present case is much more complex as there is not any steady production of locomotives. This is not due to lack of need, but the cost of construction is sufficiently great to stifle the demand and cause retention of obsolete stock. (It is assumed, in this discussion, that the conditions of the Award Program require the contestant to confine himself to industry in the country in which he resides.) Where the average age of locomotives in service exceeds thirty years, the need of new stock is sufficiently obvious and with a total stock of, say, 400 locomotives there is need to build at least twenty-five engines per year continually. In such case the gross saving would amount to more than £6,600 ($26,334). Without a drastic reduction in cost, the life of the existing locomotives must be prolonged indefinitely, carrying the concomitant of heavy maintenance expenditure. Many of the rivetted frames, however, have reached the end of useful life and are being replaced at the rate of about ten per year. On this basis, the gross savings due to adoption of this design would amount to say £2,660 ($10,613.40) or, alternatively, the replacement of frames could be accelerated considerably.

These figures, no doubt, seem very small, but they relate to a single railway system of comparatively small dimensions. Further, the design itself relates to a locomotive of medium size only to operate on the 3′6″ gauge track. Taking the percentage saving as proved at 46 per cent, the monetary saving for more powerful locomotives on wider tracks will be very much greater than shown for this particular case, but in the absence of definite evidence, the proved figure of £266 ($1,061) will be used.

The total number of steam locomotives in Australia and New Zealand is, approximately, 4,500. At an average life of 33.3 years, the replacement rate is 135 per annum and the saving is £35,910 ($143,280) per annum.

The group railways of Great Britain own approximately 22,200 steam locomotives and at the same very conservative replacement rate of three per cent, the number of locomotives built per year is 666, giving a gross saving of £177,156 ($706,850).

There cannot be any doubt that if the whole locomotive industry of the world is considered the gross saving will be more than £1,000,-

000 ($3,990,000), assuming that no railway exceeds a replacement rate of three per cent per annum and that no locomotive is large enough to show a greater monetary saving.

Increased Service Life, etc.—One of the most prevalent troubles with present-day locomotive frames is the slackening of bolts and rivets. The strength and security of bolted and rivetted joints is based on the assumption that every bolt and every rivet is perfectly tight. Under the severe conditions of locomotive service this assumption does not hold good. The welded design scores very heavily in this regard by removing this cause of repairs and time out of service. Not only is the efficiency of the frame increased, but the more rigid welded structure will serve its purpose of bedplate for the engine driving mechanism with the result that life of bearings will be increased with a distinct and considerable effect on cost of repairs and locomotive availability.

The secondary economy of the design is varied and far reaching. Machine shops in railway workshops usually are congested with work and the welded frame offers great relief in this regard. Drilling of frame members is eliminated almost entirely, while planing and milling are drastically reduced. These features have the effect of increasing machine shop capacity to the extent, in many cases, of avoiding or postponing capital expenditure on additional machines. This is a considerable, though incalculable, increase in the gross savings made possible by adoption of the design. The effect on the pattern shop due to the virtually complete elimination of castings from the frame structure must be very great and here is a further indefinite increase in gross savings.

The social advantage of reduced cost of construction is very real, not only in its direct effect, but on account of its indirect effects on the cost of transportation. In this particular case, the reduction in weight amounts to four per cent of the total weight of the locomotive and this could well be applied to increase the capacity of the locomotive, giving greater haulage and improved efficiency. Anything which tends to reduction of railway expenditure, while increasing efficiency, must be regarded as socially advantageous.

There is a further real social advantage in replacing rivetting by welding. The noise associated with everyday life in our civilization is calling more and more insistently for reduction. Railway workshops have grown very much noisier in this century with the extension of power rivetting hammers. This increase in noise is accompanied by a real and extensive reduction in efficiency and cannot have other than a deleterious effect on individuals. Nothing offers so much hope in this regard as the development and extension of the art of arc welding and this design is submitted as a contribution toward that desirable end.

Chapter II—The Importance of Welding in the Body Construction of Diesel-Electric Railroad Locomotives

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Through all the history of the various industries of mankind, probably no other procedure of joining metals has enjoyed as much attention on the part of engineers and metallurgists as that of modern arc welding. The rapid strides made in the technique of welding, together with its almost universal application, illustrate the practical value of co-operative tendencies in such widely divergent industries as those based on electrical and mechanical engineering, metallurgy, applied physics and chemistry.

This state of the art made welding of prime importance in construction of the newest developments along transportation lines where experience has established definite standards for reliability. Accordingly, the all welded structures of the latest addition to railway engineering —the diesel-electric locomotive—have added to railroad annals an unprecedented margin of safety, particularly for high speed travel. In the great past of American technical developments, not a single steam locomotive has ever been subject to the gruelling task of maintaining, daily, thousand-mile schedules at speeds unheard of a few years ago. Such performance is expected of the diesel-electric welded speedsters built since 1937!

The welded bodies of these crack trains, with their 1500 to 2500 feet of welds per car, are certainly important factors of confidence in establishing consistent reductions of travel time in excess of 35 per cent compared with the fastest steam-powered trains of former times. The undeniable endorsement of this type of transportation by America's public has finally become of a highly remunerative value to those progressive railroads, which foresaw the many advantaegs of the diesel-electric locomotive.

Since the epoch-making trip of the first three-car Zephyr train from Denver, Colorado, to Chicago's "A Century of Progress Exposition" in 1933, a rather complete change has occurred in the construction of high speed diesel-electric locomotives. Subsequent to that time the formerly used riveting and bolting of car or locomotive bodies has been supplanted almost entirely with all-welded assemblies, at least when using ferrous metals for such construction.

Accumulative experiences gained in the daily performance of the many diesel-electric speedsters under very strenuous schedules were not only responsible for the practically complete replacement of the riveted joint by electric arc welding, but they did much more than that. They were the reasons for new inevitable developments, which have since been wonderfully fruitful in important adoptions of electric arc welding in numerous other fields of commercial endeavor.

Let us stop for a few moments to scrutinize the technological advantages of welded versus riveted construction with a specific view to high speed or heavily scheduled locomotives. The advantages are:

(1) Uniform distribution of stresses throughout the car body.
(2) Very marked reduction of the weight of the locomotive in reference to its power output.
(3) Adoption of stronger materials for car body construction.
(4) Decreased cost of production.
(5) A stronger, more ductile bond between the welded members.
(6) Neater appearance.
(7) Much better resistance of joints to repeated stresses, at ordinary and subzero temperatures.
(8) Easier cleaning and painting.

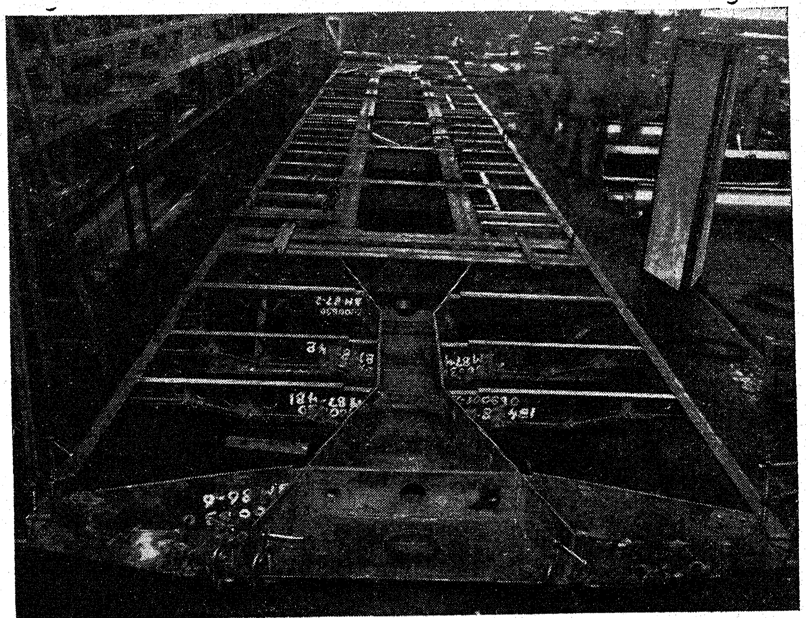

Fig. 1. Arc welded underframe of modern streamliner.

In order to fulfill these expectations, all materials entering into the manufacture of the framework of the car body are being grouped into those members which are distinctly load-bearing and into those which are not heavily stressed. Such requirements reflect themselves in the utilization of an especially developed manganese-molybdenum steel with its carbon concentration generally not exceeding 0.18 per cent The material has a high yield strength, bends and forms very nicely, has high endurance and impact properties at low temperatures, does not crack in shearing as some pearlitic manganese steels do, and welds very satisfactorily without the danger of an undue hardness gradient between parent metal and the weld. The metallurgical char-

acteristics of such low-alloy steel plates are best appreciated from a comparison with steel used in non-stress bearing carbon steel plate:

Chemical Composition in per cent	Mn—Mo Steel	Carbon Steel
Carbon	0.13	0.16
Manganese	0.91	0.44
Silicon	0.17	0.01
Phosphorus	0.016	0.012
Sulphur	0.017	0.021
Molybdenum	0.51	—
Copper	0.08	0.04
Nickel	0.07	—
Chromium	0.04	—
Nitrogen	0.019	—

Welding is carried out by selecting and using electrodes which produce deposits of such composition as those of the parent metal. Numerous tests with specimens welded by means of alloyed and plain carbon steel rods have shown conclusively that a weld, which is chemically similar to the parent metal, has invariably better physical characteristics than heterogeneous welds. With perhaps two or three exceptions, there are not yet available commercial grades of electrodes which will produce consistently a deposit with about 0.50 per cent molybdenum and a corresponding concentration of manganese. Thus, the primary problem of welding load-bearing members of diesel-electric streamliners narrows down to the selection of rather specialized welding

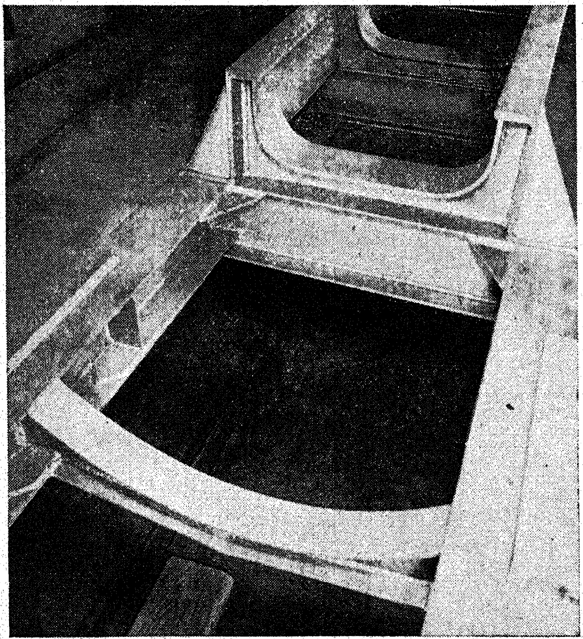

Fig. 2. Section of all-welded engine bed.

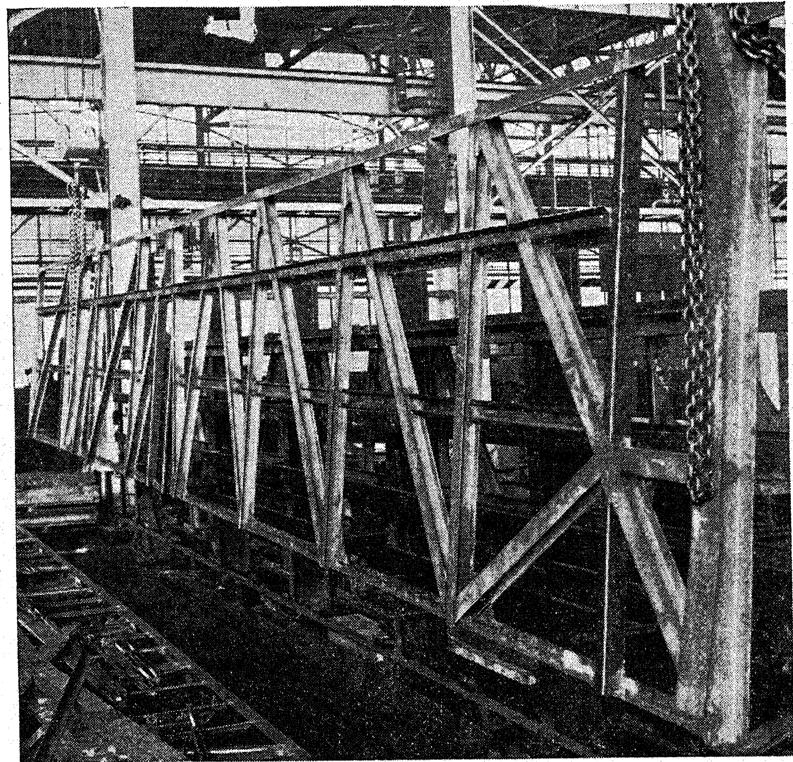

Fig. 3. Diesel-electric locomotive side frame just after completion of arc welding.

rods, suitable for making joints of predetermined chemical composition and mechanical properties.

The welding technique applied in the construction of modern car bodies follows the highest standards dictated by the fundamental necessity of absolute safety. After being carefully dimensioned and checked theoretically for the various loads it is to carry under most trying conditions, the body is constructed in its various principal parts and then assembled:

The base, or underframe, of the car—probably the most complicated of the structure—consists of a series of specially designed beams welded to two long Z-bars (See Fig. 1). Three items of loading are decisive in the limits within which the designer must primarily determine mass effects and general dimensions, viz., the loading by the two engines and two generators as well as the location of the two bolsters which transfer the entire load to the trucks, axles, and wheels respectively. A section of an all-welded engine bed is shown in Fig. 2. Rather simple fixtures for the exact location of the parts are being used in assembling the base structure. All the work is carried out on six welded supports permitting easy access to all parts above and below the fabricated base.

The side frames are similarly welded together on carefully proportioned welding fixtures, care being taken to allow for shrinkage to

finished dimensions. Some conception of this important consideration will at once be apparent when reviewing the framework of the sides in Figs. 3 and 4.

The problem of shrinkage in welding car bodies of diesel-electric locomotives must be evaluated very carefully for each type of construction. The number of welds, their geometrical outline, length, etc., are undoubtedly the most outstanding factors in predetermining the magnitude of shrinkage of the 60 to 80-foot long bodies of the locomotive. It has been found by measurements that shrinkage may be up to 1.8 per cent for composite structures, which nearly approaches shrinkage in castings.

Transverse deformative strains caused by the static loading of the underframe and side frames are mainly taken up by an especially constructed roof, which permits elastic longitudinal deformation between the bolsters, but which is practically rigid in planes perpendicular to it (See Fig. 5). These static as well as some dynamic requirements of the car body prompted the adoption of a rounded roof. That factor is naturally evident in the design and ultimate construction of the lateral and, in part, also of the longitudinal beams of the roof. Since the roof is later covered with high tensile steel sheets, the cross bearing roof supports are made of Z-sections permitting a convenient plug welding of the sheets through one end of the zee. The purchasing railroad ordinarily specifies the material of the roof sheets, but the beams are again made of high tensile or carbon steels according to load conditions. In many cases, the roof is covered with columbium-treated 18-8 stainless steel of 12-gauge; other cars are topped with 12 to 14-gauge steel of the nickel-copper type.

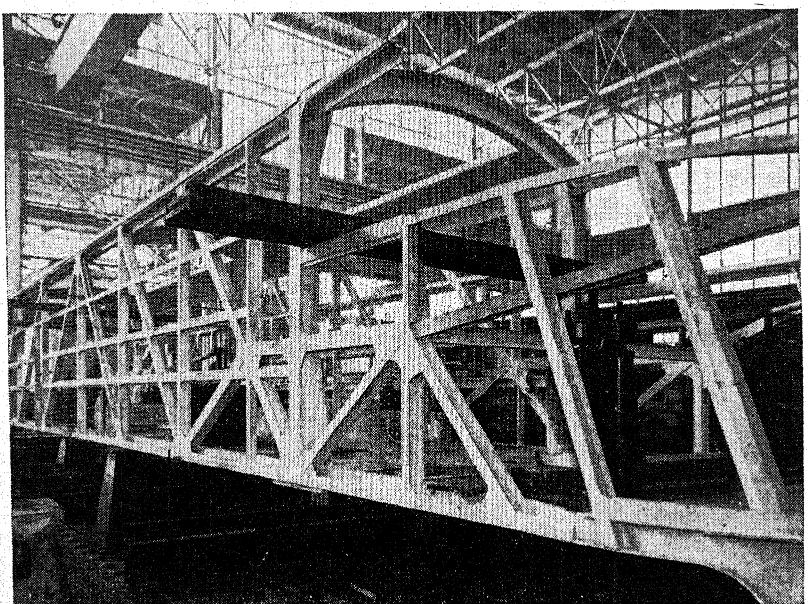

Fig. 4. Completed framework of modern streamliner.

After completion of the two side frames and the roof, actual assembly of the car body commences. One side is first removed from the welding jig and welded in an upright position to the base frame. Careful positioning is maintained by tie-rods tacked to the two frames. The other side is similarly connected to the base. While all the tie-rods remain in proper locations, the roof is finally welded in place. After adding the end sheets and additional crossrods, gussets, etc. (See Fig. 4), the tie-rods are removed and the minor parts, brackets, pipe clamps, fan frames, and similar items may then be welded as per requirements. Before installing the engines, generators, blowers, pumps and auxiliary equipment the front is built up.

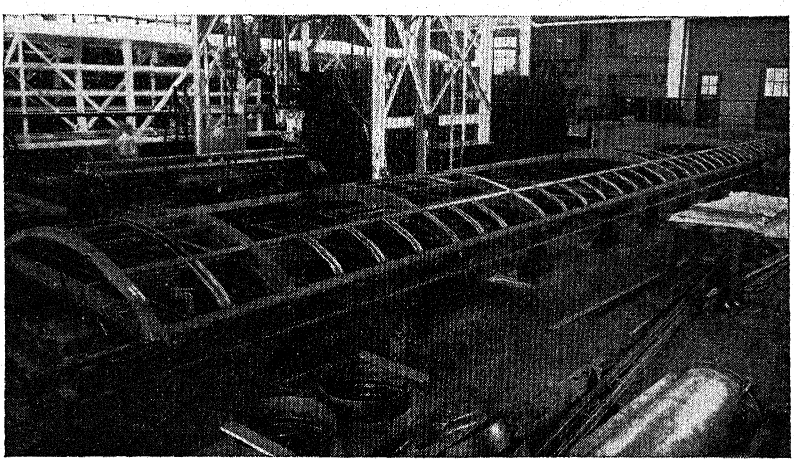

Fig. 5. Roof frame in jig for arc welding.

The "nose" of the modern diesel-electric streamliner has appropriately been patterned according to experiences gained in automotive design. As in the roof construction, a framework is first fabricated upon which the properly-shaped front sheets are welded. The latter operation is naturally plug welding in up-hand to nearly vertical position. Again the diameter of the original hole is about $5/16$ inches and the electrode used is a special 0.40 to 0.60% molybdenum rod. Fig. 4 illustrates the structure, while Fig. 6 indicates the smooth "streamlined" appearance of this portion of the locomotive just before the finishing panels of plymetal are applied to the sides of the car. The entire body is then shotblasted, inspected, and repaired wherever some doubt exists as to first-class quality of any weld.

In the meantime, fuel tanks, water tanks, sand boxes and battery boxes have been manufactured by arc welding, tested for possible leakage by experienced inspectors. These may now be welded to the frame, thus fairly completing the fabrication of the car. The hatches are then being finished—also by arc welding—and are being applied after the power plant, wiring, piping are finished. These operations are finished by lifting the car with its contents over two trucks. Electrical connections and some piping are only necessary to actually enable the

testing engineers to attempt the first trial run. Painting and trimming are then applied before final inspection, followed by more testing, and finally shipment.

In building diesel-electric locomotives either of the high speed passenger type or of the less spectacular, but equally efficient switching type, practically all commercially known processes of modern arc welding are utilized. There is no exaggeration in the statement, that the diesel-electric locomotive of today is probably the most radical departure from conventional methods of construction by means of rivets and bolts to those of modern welding.

The entire car body of diesel-electric switchers is of arc welded construction. This is especially true of the underframe, engineer's cab, tanks and many other parts. Bolts, or other mechanical joints, are

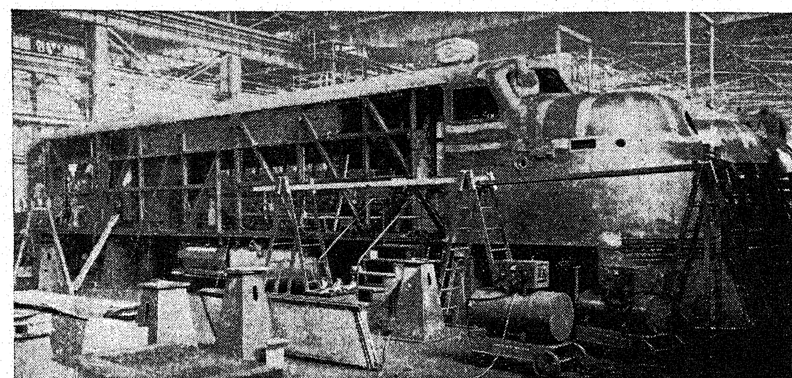

Fig. 6. Diesel-electric streamliner—all welding completed

used only for such parts requiring frequent removal, all permanent joints being made by butt or fillet welds. Wherever watertight construction is desired, such as for cab or tanks, continuous welds are applied.

Without doubt, the largest all-welded part of the modern switcher is the underframe, the size of which may best be realized from the weight of this part of the car body. The unit for a standard 100 ton-600 HP car weighs approximately 28 tons, whereas the 125 ton-900 HP diesel switcher has an underframe weighing about 44 tons.

In principle, the underframe for the 600 HP car is a steel plate 40 ft. 3 in. long, 10 ft. wide and 2 in. thick, to which two center sills 40 ft. 3 in. long, 7 in. wide and 3 in. thick besides two side sills 36 ft. 9 in. long, 7 in. wide and 2 in. thick are welded. The 900 HP frame is produced from two 4¼ in. plates, which are joined by two single bead automatic butt welds. In order to eliminate any possible cracking of the welds due to an internal notch effect, the beads overlap, thereby representing actually one solid piece of metal. Fig. 7 depicts this central butt joint. The fillet welds of the sills are continuous on both sides.

Welding stresses and deformation are eradicated by a carefully controlled heat treating process in a large gas-fired furnace. The charge

of the furnace consists of four frames of the 600 HP type or two intended for the 900 HP switcher. The straightness of the frames after heat treatment must be within $3/16$-in. over the top surface, which requirement facilitates the alignment of the engine, generator, fans, etc., during the subsequent assembly of the power plant. Both ends of the underframe are later equipped with all welded coupler pockets, which are welded to the frame in an inverted position. A $1\frac{1}{2}$ in. bolster web together with a bottom plate 40 ft. 3 in. long, 3 ft. 6 in. wide and $2\frac{3}{4}$ in. thick are then welded to the center sills. All steps and the $1\frac{1}{2}$ in. thick end plates are finally welded to the main structure of the underframe.

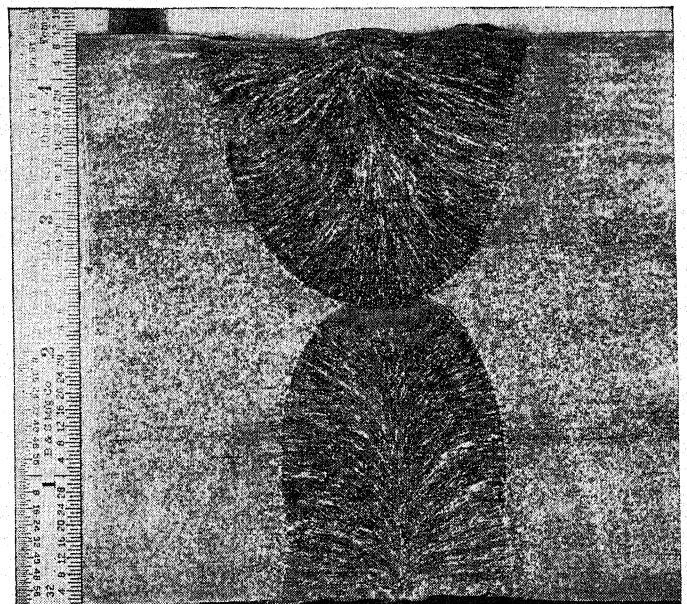

Fig. 7. Photomacrograph of butt weld in $4\frac{1}{4}$ inch underframe plate, welded by automatic arc welding.

All exposed welds are ground flush by means of portable grinding disks. A final inspection is made of all joints before the frame is turned over to the assembly department. There the base is placed on suitably designed welded supports, which arrangement permits a convenient access to above and below the top surface. This operation is followed by the installation of the welded engine bed, the welded cab, fan housings, etc. A 26 ft. 9 in. long hood finally encloses the entire power plant of the locomotive.

The actual duration of service so far is not sufficiently long to justify any prediction as to the practical value of all the precautionary measures taken by the builders of the predominant diesel-electric units in the world to insure the greatest possible safety of passengers, crew and equipment. Nevertheless, the most up-to-date means of ascertaining

the suitability of metals for high-speed transportation are being used in preliminary studies as well as tools of metallurgical inspection throughout the construction of this newest type of passenger-carrying equipment.

Further assurance of a reliable car construction is attained by periodical classification of welding operators according to a definite procedure of observation and final testing of the welded stock. All electrodes used in the fabricating department must also pass rigid metallurgical control standards. Unbiased information is finally obtained by making photo-elastic studies of the various adopted types of welds. Careful tensile tests of actual welded specimens confirm the findings of these optical studies before applying the technique in question when fabricating the locomotive body.

Stress Relieving.—In practical opposition to the universally acknowledged fact that no weld is produced without some complex residual stress in the adjacent metal, stress relieving at temperatures up to 1250°F is considered broadly as a procedure whereby internal stresses are minimized or eliminated entirely. All academic as well as practical welders realize, however, that the effects of such residual stresses may be quite serious if not detrimental to the ultimate usefulness of welded structures. Hence, it is customary to stress-relieve as many welded parts of the structure as is practical.

All welded beams of the underframe for high-speed locomotives, fan-housings, crankcases, etc., are therefore subjected to the thermal cycle, care being taken to permit a thorough soaking at temperature, followed by slow cooling in the furnace. The actual time of heating, soaking and subsequent cooling to 200 to 300 degrees Fahr. is governed by the weight and thickness of the charged pieces. The furnace used for these operations is gas fired and its operating chamber measures 74 ft. in length, 13 ft. in width, and has a 9 ft. high effective clearance. The temperatures are automatically controlled in four zones and the draft is also stabilized by means of a special controlling device. The furnace operators maintain elaborate records of operating conditions, thus permitting the metallurgical department to ascertain the exact metallographical conditions of the stock as it leaves the furnace. Without doubt, this knowledge is quite tacit in the future everyday performance of the finished locomotive.

Testing Materials and Welds for Diesel-Electric Locomotives.—Many conditions enter into the selection of the design, materials, and methods of fabrication of such important power units as are represented by today's diesel-electric streamliners. Static, as well as dynamic requirements, are put forth upon most materials used in the construction of these locomotives. Hence, in analyzing the material requirements for particular purposes, a multitude of tests is generally essential before intelligent decisions may be made by the designing engineers.

Besides the conventional chemical tests, macro and microscopic examinations, grain size, tensile tests, bend tests, and hardness tests, it becomes also imperative to investigate other dynamic properties.

As a safety precaution, impact tests are made with welds and metals at ordinary and sub-zero temperatures, thus simulating mechanical reactions at certain train speeds. A new type Charpy, Izod, and tensile-impact testing machine is used for these investigations.

Similar attention is paid to the endurance properties of steels and welds under repeated stresses. Experience has indicated that the simple

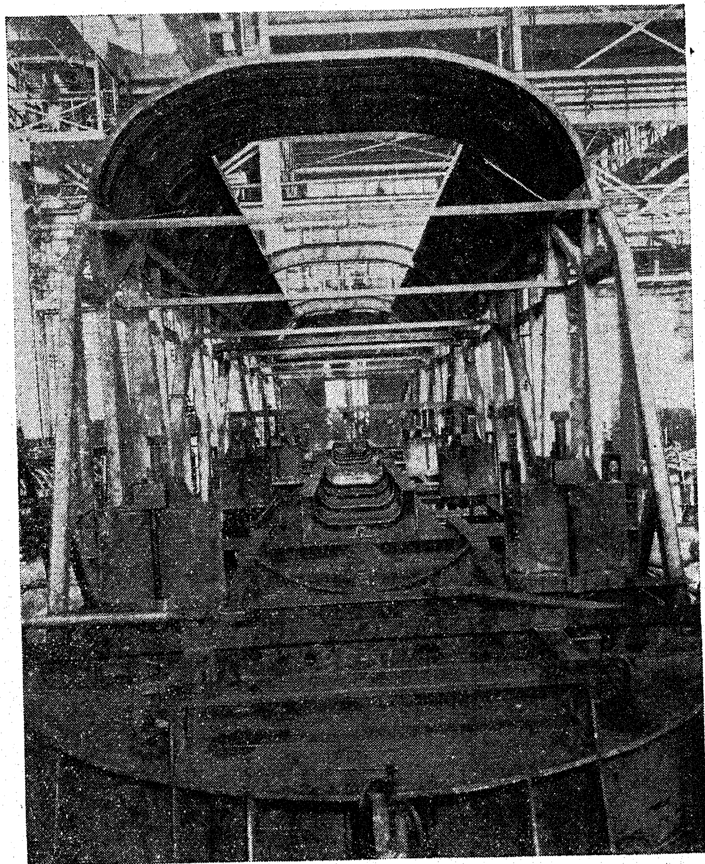

Fig. 8. Car body of streamliner prepared for loading test.

load-deflection principle of testing is preferable to the rotating beam test, the latter type of loading being better applicable to axles and similar rotating pieces of machinery. Since the test specimens are so designed for simple reversal to represent a constant, this type of test is especially adoptable to investigating the behavior of welds. Very interesting and useful information has been obtained from this work. Any specimen not failing below 10,000,000 cycles or reversals is considered satisfactory, i.e., having stresses below the fatigue limit.

Testing the Safety of Welded Locomotive Bodies.—As indicated in the introductory paragraphs of this paper, the car or locomotive body of the modern streamliner is fundamentally a framework or skeleton of beams joined by arc welding. Rather complicated mathematical relationships between loading, stresses and deflections have been developed by the designing engineers, which calculations have proved of inestimable value in the development of new and more efficient types of diesel-electric high speed locomotives. In the wake of these calculations, engineers and metallurgists have conceived a procedure of ascertaining actual conditions by imposing synthetic loads and measuring the resultant stresses and deflections in important members of the body. (See Fig. 8). All such investigative work requires a metallic finish, i.e., shot-blasted surfaces of the entire structure, as well as skilled technicians and ample facilities for accurate measurements. In principle, the "safety" test consists of the following phases:

According to a predetermined schedule, loads are applied in various locations of the structure simulating those of actual operating conditions; these loads are produced by manually operated loading jacks, which were previously calibrated in a compression-testing machine of the metallurgical laboratory. As many as sixteen of these jacks may be used in conjunction with one series of tests. The loading is conducted on actual or 100 per cent pressures, followed by 125, 150 and 175 per cent of actual working loads. After reaching these loads, careful examinations of all welds are made by inspectors and engineers. During all tests conducted so far, not a single defective weld has been discovered, thus proving the accuracy of calculations as well as reliability of workmanship!

Relative Economies of Welded Construction in Diesel-Electric Railway Transportation.—In order to delve into the problem of proportionate cost and ultimate operating economies brought about by the advent of the diesel-electric locomotive, let us first compare the actual developments of the last year* with those difficulties, which confronted the pioneers in the early attempts to adopt diesel power for railway transportation.

The original diesel-powered switcher in the United States was built some fourteen years ago, but the 300 HP unit was by far too heavy in proportion to the 60-ton nominal weight of the locomotive. It was not until about 1932 that a really light weight crankcase supplanted the very substantial casting, which, because of welding and many additional changes in the metallurgy of the diesel engine, reduced the weight per BHP to commercially feasible limits. A review of these factors, which made especially the high-speed diesel-electric locomotive a practical reality, would not be complete without some reference to the technical fact, that the re-adoption of riveted joints instead of welded ones would add at least 25 to 30 per cent to the weight of the modern streamliner.

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*At time of writing paper.

Almost needless to assert, this difference would obviously affect the operating balance sheet very markedly.

Another first cost saving has been effected by the use of many welded structures instead of steel or iron castings. For example, the single item of a welded underframe versus a cast steel frame reduces the cost of a switching locomotive nearly three per cent. If additional comparisons were made with many other welded against cast parts, this difference would certainly amount to well over 10 per cent in initial cost saving alone, without even considering weight reduction in favor of the welded construction nor the undeniable improvement of reliability and safety of the welded portions of the locomotive.

In justice to the traditional steam locomotive—including those of most advanced designs—with a multitude of castings, bolts and rivets, it is somewhat difficult to define what may be considered as proportionate cost saving of the welded car body. Pecuniary savings accruing to the railroads from the adoption of diesel motive power may perhaps best be realized from the following tabulation of operating costs of various switching locomotives, wherein maintenance costs are significant, because they undoubtedly include items governed by the negligible attention given to car bodies:

HOURLY OPERATING COSTS OF VARIOUS SWITCHERS

Item	Steam Switcher	Oil-Electric Switcher 300 H.P.	Diesel-Electric Switcher 600 H.P.	900 H.P.
Wages	1.70	1.70	1.70	1.70
Fuel	1.05	0.22	0.22	0.34
Water	0.08	—	—	—
Lubrication	0.02	0.25	0.08	0.13
Maintenance	1.35	0.21	0.22	0.16
Supplies	0.02	0.02	0.02	0.02
Insurance	0.01	0.02	0.02	0.02
Roundhouse exp.	0.30	0.05	0.05	0.05
Average Cost	4.53	2.47	2.21	2.42

Note: The wages of "firemen" are included for all types, although their services are not essential for the oil- and diesel locomotives.

As indicated, the most impressive advantage of welding in the construction of diesel-electric switchers is that of maintenance. Steam locomotives demand practically a 24-hour hostler service, whether they are in operation or not. Proper boiler efficiency and supervision of mechanical equipment of the steam locomotive require a regular repair force, which crew is frequently augmented when some work has to be rushed through or when the task is too heavy for the repair gang to carry out. In addition, the fire boxes of conventional steam engines must be replaced every few years, which expenditure is naturally eliminated in diesels. The welded underframe, cab, tanks, supports, etc. of diesel switchers do not require any appreciable attention at all, except for cleaning and painting. Even the customary periodical inspection of the car body structure has been dispensed with in most railroad yards

due to the absolute reliability of the welded structure. This cannot be said in reference to riveted steam locomotive parts nor about the various castings used in their manufacture.

Even the most ardent conservatives in America's railroad directorates admit, today, that the spectacular diesel-electric streamliners as well as the nearly always available diesel-electric switchers have made the public again railroad conscious. This change of attitude is admittedly a logical derivative of the consistent performance in regard to distance or time together with a proven reliability of the equipment. Both items are, in turn, functions of an advantageous combination of the diesel engine and electric drive together with the application of welding and of new metals in the design of the rapidly accepted locomotive. It is finally interesting to note, that even the steam engine of yesterday has been given a welded streamlined covering so as to make it, at least, look modern! The welded diesel-electric streamliner has thus proven to be a most effective impetus for safer, more economical and more interesting railway transportation

Chapter III—Design and Cost of Locomotive Boiler of Fusion Welded Construction

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The subject matter of this paper is the redesigning of a steam locomotive boiler from riveted and screwed-stay construction to complete fusion welded construction.

Fusion welded steam boilers for locomotives have not been designed for welded construction and sold in the open market or generally used prior to Jan. 1st, 1937. To the best of the author's knowledge permission to build only one steam locomotive boiler having all joints fusion welded has been granted by the Inter-state Commerce Commission and that one boiler was built by the American Locomotive Co. the fusion welding of it being supervised by the author.

The design is explained in this paper and by the drawings.

General Advantages to be Obtained by Fusion Welded Construction of Locomotive Boilers as Compared to Riveted Construction.— The natural disadvantages of riveted and screwed-stay construction for locomotive boilers have long been appreciated but up to the present time* they have been accepted as necessary evils, inherent to what was (and among railroad men still generally is) considered the best method of fabrication.

There is no doubt in the mind of the author or in the mind of any engineer who thoroughly understands fusion welding as performed by skilled operators to the requirements of the A.S.M.E. Boiler or other pressure vessel Codes as to the ability of properly designed and welded joints made by its use to better withstand any stress the riveted joint may be required to withstand and to resist corrosion to a considerably greater degree. This has been proved many times. To an engineer having a good knowledge of locomotive boiler construction, coupled with the aforementioned understanding of fusion welding, the advantages to be gained by using this method of construction for locomotive boilers are very apparent.

Corrosion is a very common condition affecting the metal of locomotive boilers. It may be explained as the eating or wasting away of the plates or other parts under the chemical action of the boiler feed water or gases. Corrosion is probably the most destructive of all the agencies that tend to shorten the life of a locomotive boiler. It attacks the boiler internally and externally, presenting itself in three forms as uniform corrosion, pitting or honey-combing and grooving.

Uniform corrosion occurs around rivet heads and stays and in the plate in general and results in its gradual thinning.

Pitting or honey-combing results in a corroded condition of the plate, usually in the location shown in Fig. 1, or it may also occur in stay-bolts or the adjacent plate as shown in Fig. 2.

*At time of writing paper.

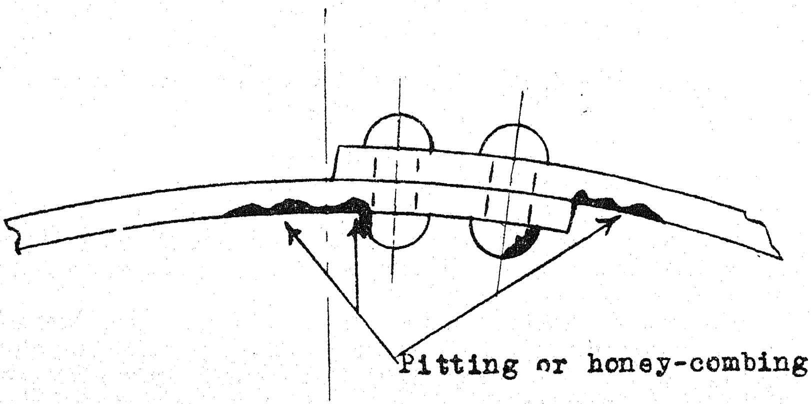


Fig. 1. In riveted boiler, pitting, or honey-combing, results in a corroded condition of the plate in locations indicated by arrows.

The uniform corrosion at rivet heads and pitting as shown in Fig. 1 and Fig. 2 is caused by the accumulation of corrosive elements at rivet heads, edges of plates, in crevices between the staybolt thread and sheet and in staybolt threads.

A fusion welded boiler having no rivets, no overlapping plates and no threaded staybolts, will offer none of these points for the accumulation of corrosive elements and having correspondingly better circulation, will, therefore, largely or completely eliminate damage due to these types of corrosion.

Grooving is a combination of physical action and corrosion. It generally occurs along horizontal lap joints as shown at "a" Fig. 3.

Grooving is caused first by the bending of the plate "b" when the boiler is under pressure and the under-lapping plate "c" slightly distorts the cylindrical shape of the shell. The bending causes small cracks to form in the over-lapping plate "b" and these cracks are then readily acted on by the corrosive elements in the water. After corrosion sets in, the cracks are soon deepened into grooves. The plates at the mud ring often develop grooves as shown in Fig. 4.

It is to be noted that grooving generally occurs where an abrupt

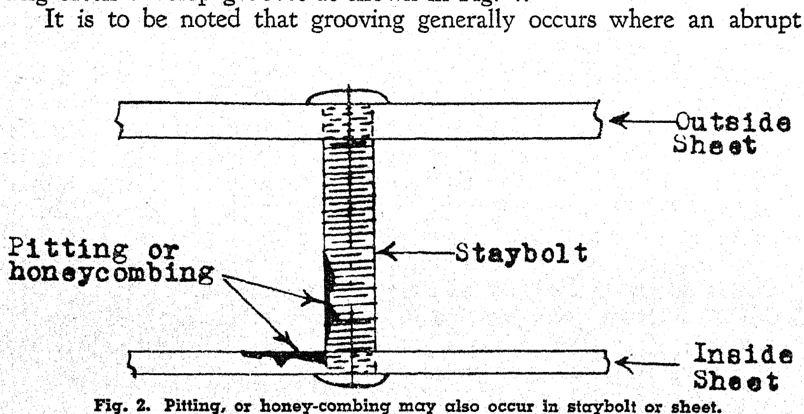


Fig. 2. Pitting, or honey-combing may also occur in staybolt or sheet.

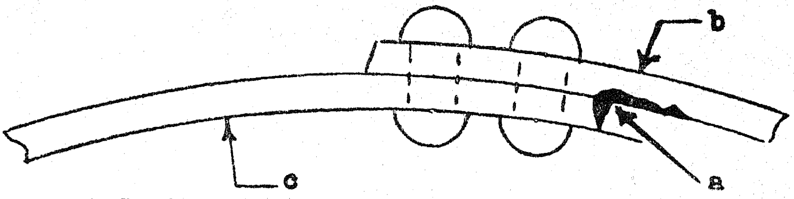


Fig. 3. Grooving, in riveted boiler, usually occurs along horizontal lap joints.

change in cross-sectional area sets up a severe concentration of stresses. Riveted construction cannot avoid these changes in cross-sectional area because the basic principle of that construction is over-lapping plates. The boiler constructed by fusion welding, having no over-lapping plates, eliminates undue concentration of stresses due to abrupt changes in cross section and the cracks caused thereby which in turn largely or entirely eliminates grooving.

Leakage at rivets and the caulking edges of seams may be caused by over caulking, careless handling of the caulking tool, rapid contraction and expansion of the boiler (due to the rush of cold air through the fire door into the fire-box or other causes such as draining hot water and refilling with cold while the boiler is still warm, etc.)

Fusion welded joints which require no caulking and have no rivets, completely eliminate this type of defect.

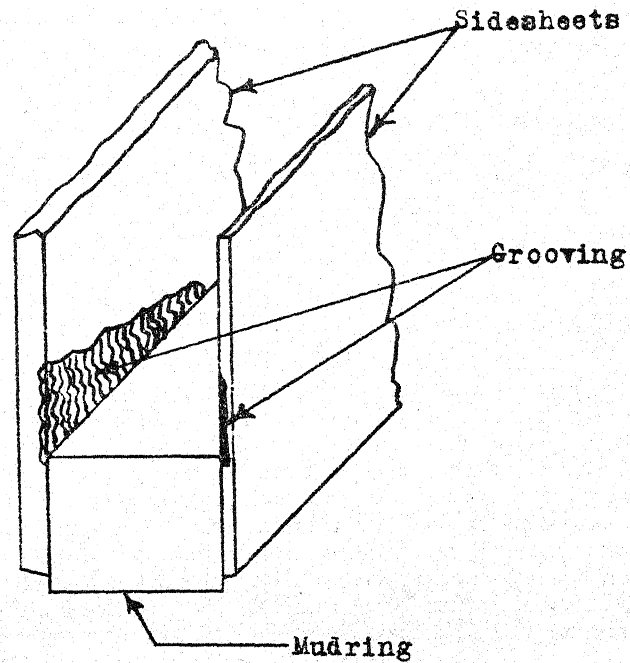


Fig. 4. Plates at mudring of riveted boiler often develop grooves.

The action of heat on boiler seams and stayed parts and the continual stresses in the boiler materials resulting from rapid expansion and contraction will cause the metal to crack at lap joints and around rivet and stay holes. These cracks run from one rivet or stay hole into the sheet or to the next hole or from a rivet hole to the edge of the sheet. This is particularly noticeable in the fire-box lap joints where they are called "fire cracks" and are caused by the inability of the cooling effect of the water to penetrate the fire box sheets at the lapped joints due to the extra thickness of metal at those locations which causes these riveted joints to overheat and crack.

There are 3337 rivets, 3342 screwed stays and 224 studs in the riveted boiler. This means there are 11,382 more holes, each one an incipient crack or leak, in the riveted boiler than in the one of welded construction. Practically all cracks in a locomotive boiler of riveted and screwed stay construction start in rivet, stud or staybolt holes and by providing a type of construction (welded) which eliminates the rivet, stud and staybolt hole and the double thickness of metal at lapped joints, the primary cause for almost all leakage and cracks and subsequent repairs is removed.

In short, the tensile strength of the welded joint (staybolt, firebox sheet, etc.) is at least that of the parent metal and can be expected to last as long as the boiler itself, remaining absolutely tight during its entire life and requiring no repairs or attention of any kind because it is made of metal similar to the plate and fused solidly with it to make the welded boiler one continuous, homogenous piece of steel having no joints depending on friction (caulking) or grip for tightness or strength.

By comparison, a riveted and screwed stay-type boiler requires caulking to provide tightness, renewal of rivets and tightening of stays periodically and continual attention to keep it tight, all of which costly item of upkeep can be eliminated by welded construction.

A comparison of the resistance to explosion due to an over heated crown sheet will show the welded design to have the greater. The reason for this is that, in the application of screwed crown stays, the stays are screwed in tightly, thus putting the metal adjacent to the holes under a strain and cause it to grip the staybolt and keep it tight. In other words, the particles of metal in the crown sheet immediately around a crown stay and the adjacent portion of the crown stay itself will be crowded closer together than those farther away.

As soon as the absence of water causes the crown sheet to begin to heat up, an annealing action takes place and the elasticity of the crown sheet around the stay is removed, (or the grip between the sheet and the stay relaxes), so that the particles of metal that formerly were crowded closely together at the stay and sheet will begin to move toward an area where they are not in such close contact. As soon as this action starts, the stay loosens and steam will begin to leak through. A continuation of the heating action softens the plate so that it will be bulged downwards by the internal pressure in the boiler. The bulging enlarges the holes around the stay and if continued long enough the sheet will be pulled off the end of the stay, this action being assisted by the crown stay itself becoming soft.

The action that follows the overheating of a screw-stayed crown sheet

is therefore progressive. First the sheet anneals and the joint begins to leak at the crown stay, next the sheet begins to bulge downwards around the stays and finally pulls away from them. It is to be noted the failure occurs at the joint which depends on friction or "grip" for its tightness.

In applying the welded stays, they are pushed or lightly driven into position, welded and stress relieved with the boiler. There is no joint depending on friction or "grip" for its tightness but rather a solid continuation of metal from roof sheet through the stay to the crown sheet.

The action that would follow the overheating of a crown sheet having welded stay construction would be a bulging of the sheet which would continue to the point of either rupturing the sheet between the stays or breaking the stays themselves. Because of the absence of joints depending on friction or "grip" for tightness and due to the continuity of metal from the roof sheet through the stay to the crown sheet, it would take considerably longer time for this action to take place than the action causing failure of the screwed crown stay construction and thereby give the engine crew a longer time to either take remedial action or escape.

Explanation of Welded Design.—In designing this fusion welded boiler two basic principles have been adhered to as closely as possible; Principle 1, a butt joint is the strongest and one of the simplest to make. It can be radio-graphed the easiest and, when chipped and ground flush with the plate, produces the smooth surface desired. Principle 2, the absence of projections, hollows or crevices on the inside of the boiler are of great advantage in that corrosion is decreased due to better circulation and lack of crevices and depressions for corrosive elements to concentrate in.

In general, all pressure seams are made by the use of butt joints in accordance with principles one and two. The extra or annealing layers of weld metal R and R^1, (Fig. 5), are for the purpose of refining the grain structure of the weld metal in the layers under them. The reinforcement is removed before radio-graphing, leaving the weld metal of the joint with good grain refinement, thus assuring high resistance to corrosion and shock. The reinforcement is removed to facilitate radio-graphing, eliminate abrupt change in cross sectional area, and provide a smooth surface. Details of butt joints are shown in Fig. 5.

The joint efficiency of the long seams on the unstayed portions of the welded boiler is taken at 90% of the plate strength per Par. 102, Section 1 of the ASME Boiler Construction Code for Power Boilers, 1933. Using formula in Par. 180, same section and Code, the allowable working pressure in pounds per square inch $= \dfrac{\text{T S times t times E}}{\text{F S times R}}$

in which T S = Ult. tensile strength pounds per sq. in. of steel plate = 55,000.

t = Minimum thickness of shell plate = 1.0625″

E = Efficiency of long joint = .90

F S = Factor of Safety = 5

R = Inside radius of weakest course = 49.5″

substituting we have;—The maximum allowable working pressure in pounds per square inch $= \dfrac{\text{55000 times 1.0625 times .90}}{\text{5 times 49.5}} = 212$

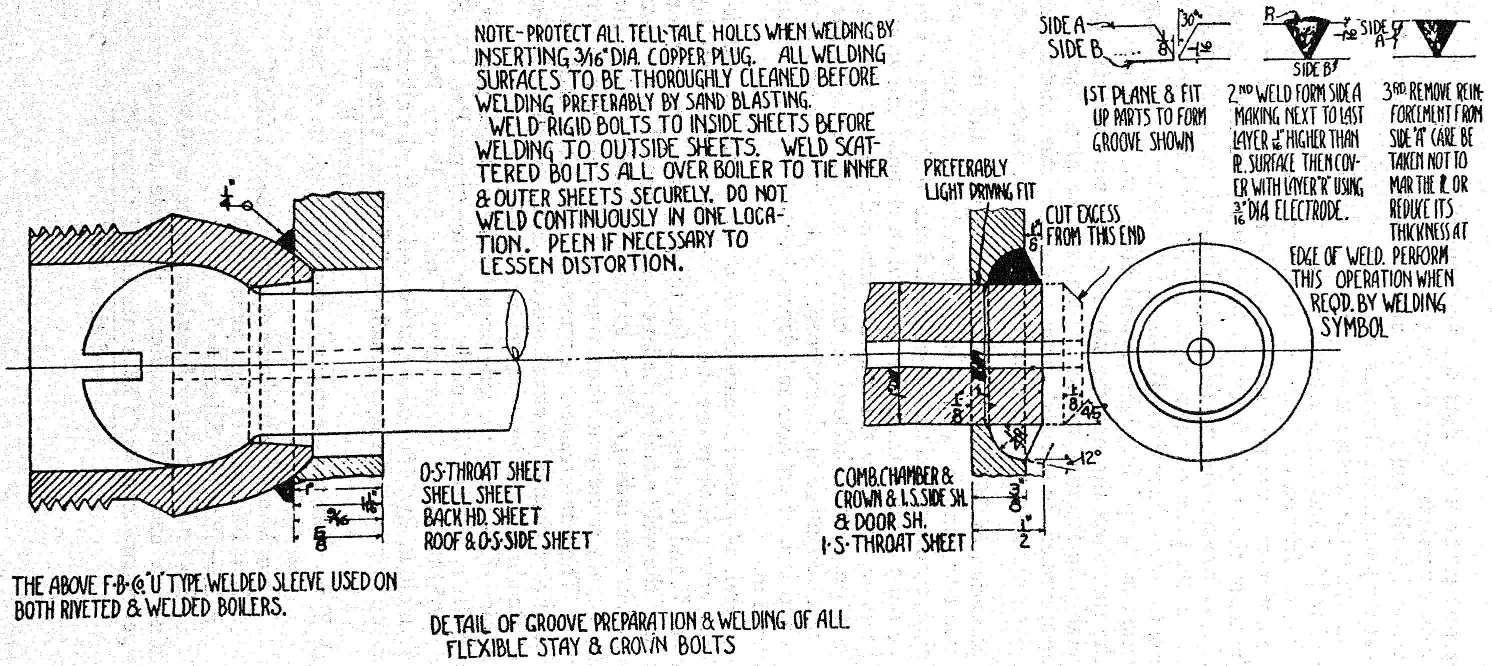


Fig. 5. Details of construction—arc welded locomotive boiler. See also page 221b.

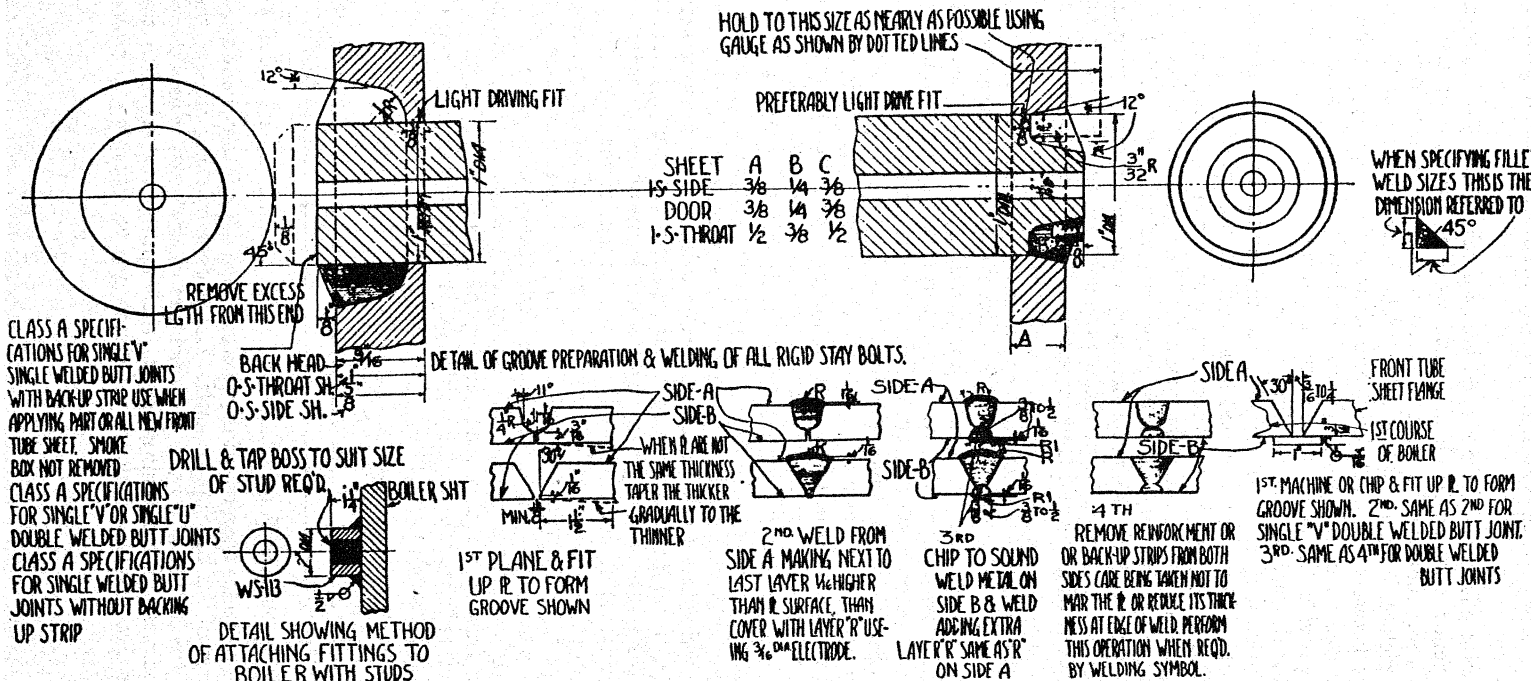


Fig. 5. Further details of arc welded locomotive boiler. See also page 221a.

The joint efficiency of the riveted boiler is taken at 89%. Thus, the joint efficiency and maximum allowable working pressure of the two boilers is approximately the same, say 210 pounds per square inch.

A single welded butt joint without back-up strip is used at the door hole joint between the back head and door sheet. This type joint is necessary due to inability to chip and backweld the "B" side of the joint. It provides ample strength as the reinforcement is left on to compensate for the lack of back welding inside.

The inside firebox sheets are joined to the mud ring by the standard double welded butt joint, chipped flush and radio-graphed.

The O.S. firebox sheets are joined to the mud ring by a single welded butt joint chipped flush and radio-graphed. The single welded butt joint is used because it is impossible to chip and backweld the "B" side of this joint. A good welder using the necessary care will procure complete penetration on this type of joint and the radio-graphs will detect any lack of penetration which would have to be chipped out from the outside and rewelded.

The butt joint was used to join the I.S. and O.S. firebox sheets to the mud ring because this type joint allows the thickness of the sheets and mud ring to be made the same, thus avoiding crevices and abrupt changes in cross-section (due to lapped plates) and the resultant concentration of stresses and grooving of the plate which is common at this location, (See Fig. 4), in riveted boilers.

Referring to detail of mud ring WP 33, shown in Fig. 6, it will be noted the thickness of the edge, corresponding to the plate to which it is welded, continues at that thickness for a short distance and then is gradually merged into the sloping surface of the mud ring by a generous radius which also avoids an abrupt change in cross-section and the resultant objectionable concentration of stresses. The surface of the mud ring slopes from the sides to the center to form a trough to concentrate sediment, scale, broken bolts, etc. at center for easy removal. A 3″ x 5″ handhole is provided at each corner to permit some degree of visual inspection and easy removal of broken bolts but as the bottom of the holes are 1″ above the welded joint, considerable of a dam is formed which interferes with complete drainage and it was felt that drain holes should be provided. The metal removed in drilling the drain holes is compensated for by building up a boss around the bottom of the hole. The material is changed from cast steel in the riveted type boiler to all fusion welded, rolled steel construction in the welded boiler and a saving in cost of $1,050.27 is effected in addition to the other advantages mentioned.

COST COMPARISON

Riveted boiler	**$10,352.98**
Welded boiler	**9,302.71**
Savings by arc welding	**$ 1,050.27**

Design of boiler opening reinforcements have the reinforcement as an integral part of the boiler plate itself. This is done by using plate of the necessary thickness to provide the thickness of the shell plus the required thickness of the reinforcement, then cutting the edges to the shell plate thickness, beveling for a welding groove, crimping to radius

and fitting and welding, using a double welded butt joint in accordance with principles one and two. This design gives a strong one piece construction with a minimum of welding.

The dome WP 10 is welded to the dome course WP 9 as shown and explained in Fig. 6, the double welded butt joint being used. The dome liner WP 11 is located on the outside of the boiler in accordance with the second principle, page 221.

The injector nozzle is modified for welded construction to conform to principles one and two. The reinforcement is cast integral.

Cast construction is also retained on the smokebox inspection opening rings because the fastening lug retaining the cap closing these openings is formed by a projection cast integral with them, usually in the form of an inclined plane. The flange is dispensed with for welded construction. A fillet weld is used to join them to the smokebox.

The front tube sheet is welded to the first course in accordance with principles one and two. Provision is made for renewing part or all of this tube sheet by the modified design of smokebox. This design allows room for easy removal and replacement of the tube sheet and for work on the smokebox side of the tube sheet welded joint so a back-up strip can be used when welding replacements and removed if desired.

The welding of the backhead gusset stays is designed to give complete penetration and eliminate any opening or "pocket" between the end of the brace and the sheet per principle two.

Front tube sheet stays are designed to allow welding all around to seal the space between the shell and the foot from corrosive action. The welding of the braces to the front tube sheet is per principle one.

Boiler braces and brace lugs are changed from forged and cast steel construction on the riveted boiler to built-up welded construction of rolled steel on the boiler of welded construction which provides equal or greater strength and reliability at about one-half the cost.

Welded flexible staybolt sleeves are common to both boilers.

The object of the welded staybolt design, in addition to providing a leak-proof, full strength joint, is to eliminate in-so-far as it is possible, the crevice which exists between the first one or two threads at the sheet and the bolt in the screwed design in accordance with principle two, thus reducing or eliminating honey-combing at that location. (See Fig. 2). This is difficult to do 100 percent due to the inability to backweld. However, with the new design and proper care in welding, this crevice will be completely or nearly completely eliminated and offer much less lodgement for corrosive elements than the screwed-stay type.

Referring to Fig. 5, the best design of welding groove is that on the firebox end of the rigid bolts in that the grooves are formed mainly by reducing the O of bolts at that end. This forms a groove which, due to its shorter circumference, requires much less weld metal than the groove used at the outside end of the rigid bolts and at the welded ends of the flexible bolts and which is formed by counter-boring the sheet. However, if both ends of the rigid bolts or the welded ends of the flexible bolts were reduced (in the same manner as the firebox end of the rigid bolts) the distance between the shoulders or the points of contact with the sheet (or sleeve) would have to be held too close to be practicable and the $\frac{1}{8}''$ bearing shown would not be held consistently. Therefore, it was

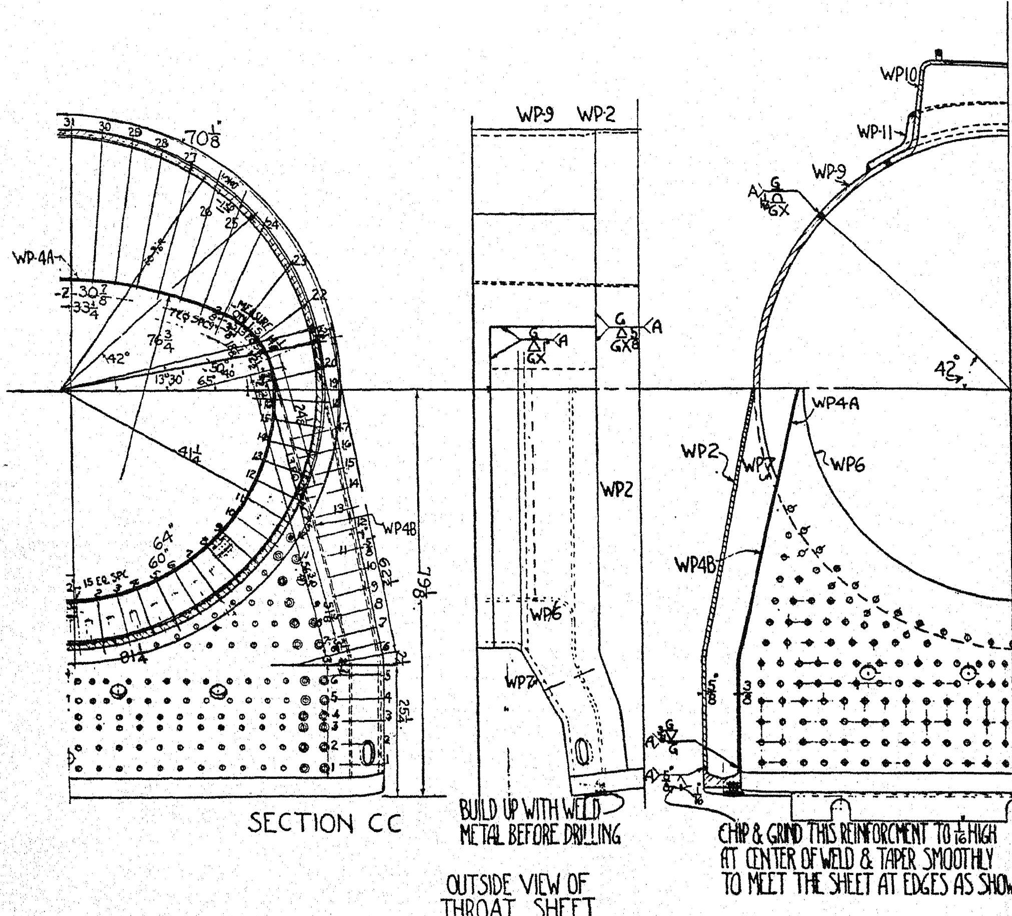


Fig. 6. All-welded locomotive boiler—details and cross sections. See also page 223b.

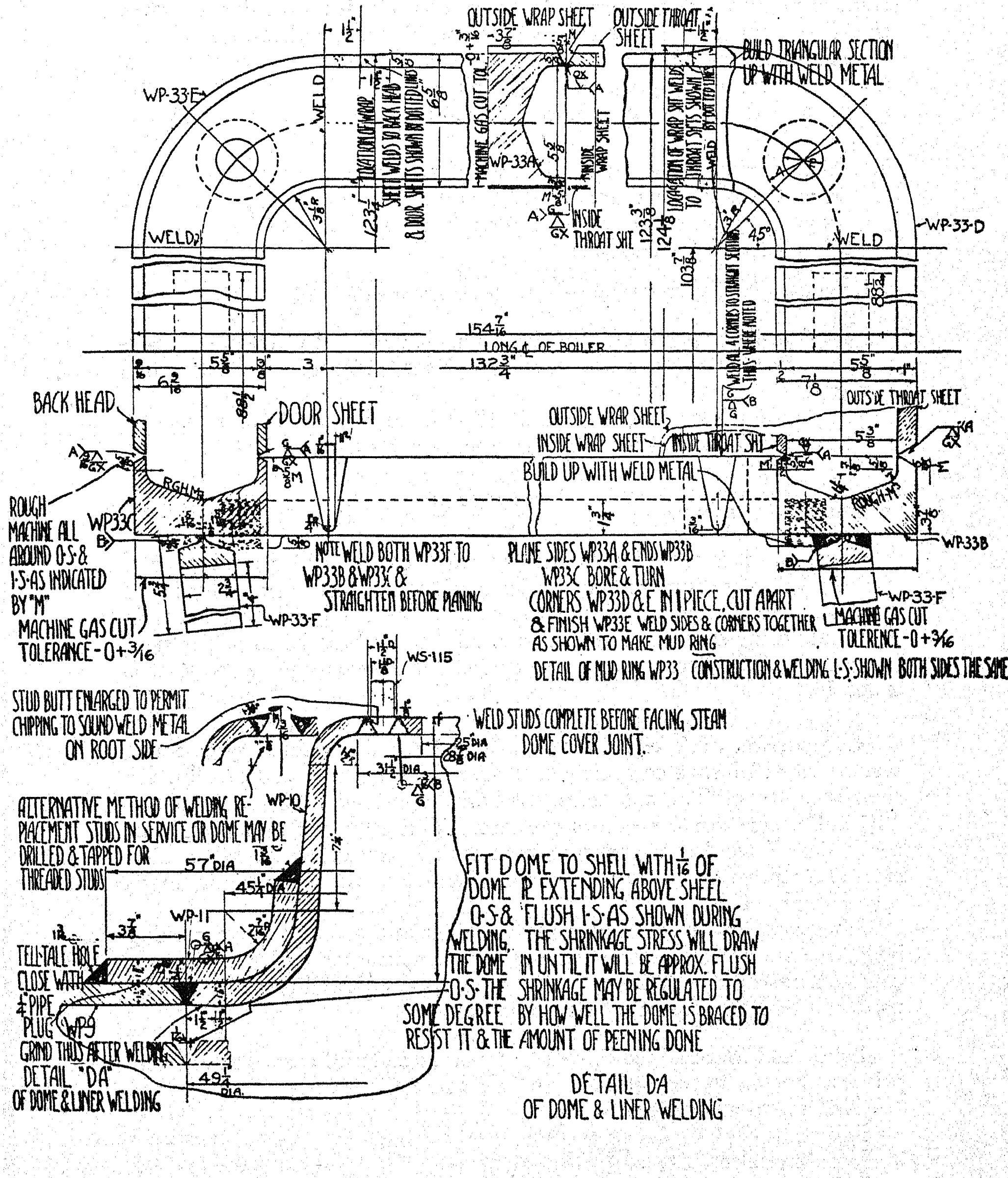


Fig. 6. All-welded locomotive boiler—details and cross sections. See also page 223a.

considered best to take advantage of the better design on the lighter sheet where the tendency to warp due to welding is greater. The outside sheets are counterbored for the rigid bolts and the inside sheets are counterbored where the flexible bolts are used. This allows normal variation in length of the bolts and permits rapid, easy application.

Allowing for $\frac{1}{16}''$ penetration of weld, the cross-sectional area of the 1" dia. rigid staybolt joint on $\frac{3}{8}''$ plate = .3125" x 3.1416" = .9817 sq. in. and its resistance to shear is found by the formula $y = \frac{A \times Ts}{FS}$

in which y = total resistance to shear of welded joint, required.

A = Cross-sectional area of joint = .9817 sq. in.

Ts = Ultimate shear strength, pounds per sq. in. = 44,000.

FS = Factor of safety = 5.

substituting, we have $y = \frac{.9817 \times 44000}{5} = 8639$ lb.

The tensile strength of a 1" dia. staybolt with 3/16" tell-tale hole is found by the same formula in which y= Tensile strength of 1" dia. stay, required.

A = Net cross-sectional area of 1" dia. staybolt = .7578 sq. in.

Tt = Ultimate tensile strength, pounds per sq. in. = 55,000.

FS = Factor of safety = 5.

substituting, we have $y = \frac{.7578 \times 55000}{5} = 8336$ lb.

From this it is seen that the shear strength of the welded rigid staybolt joint in $\frac{3}{8}''$ plate is more than the strength of the bolt itself. This is the weakest welded staybolt joint in the boiler, the flexible staybolt joints in $\frac{3}{8}''$ plate being stronger due to design and the welded joints of the rigid bolts in the O.S. sheets being stronger due to the heavier plate the joint is made in.

Comparison of Weight.—The material for the welded type boiler weighs 99,318 lbs. as compared to a material weight of 110,278 lbs. for the riveted type. The net weight of both boilers would be less but the 10% difference would be about the same. This 10% saving in weight in the boiler of welded construction is especially advantageous when considered with reference to the present trend toward light-weight, high-speed locomotives.

No special effort was made to save weight in the design of the welded boiler by the use of material having higher tensile strength and greater corrosion resistance. Most of them are of good weldability and could be used in a boiler of fusion welded construction.

Labor and Material Costs.—In arriving at material costs, the current prices as known to the author were used for the following:

Steel plates and shapes,
Rivets,
Welding electrode,
Bolts,
Studs,
Staybolts.

Casting and forging costs were estimated by the author who has had considerable experience in estimating and costs and feels competent to do this class of work.

Freight cost is shown in the following tabulation:

FREIGHT COST—RIVETED BOILER

Freight cost to Dunkirk, N. Y.

FROM

Lebanon, Pa.	Cleveland, Ohio	Pittsburgh, Pa.
Steel cast'gs, 4665 lbs. Freight cost, $18.66	Rivets, 5208 lbs. Freight cost, $15.10 Welding electrode, 294 lbs. Freight cost, $1.09 Misc. studs, keys, etc., 279 lbs. Freight cost, $ .82	Stay bolts, 15426 lbs. Freight cost, $49.36 Steel forgings, 1875 lbs. Freight cost, $6.00

Total freight on material for riveted boiler (not including rolled plates and shapes) $91.03

WELDED BOILER

FROM

Lebanon, Pa.	Cleveland, Ohio	Pittsburgh, Pa.
Steel cast'gs, 176 lbs. Freight cost, $ .70	Welding electrode, 3056 lbs. Freight cost, $11.31 Misc. keys & studs. 237 lbs. Freight cost, $ .76	Stay bolts, 15428 lbs. Freight cost, $49.37 Steel forgings, 350 lbs. Freight cost, $1.12

Total freight on material for welded boiler (not including rolled plates or shapes) $63.26

NOTE: Freight on rolled plates and shapes not included in above figures because prices quoted by the steel mill included freight to Dunkirk.

Engineering expense based partly on the time spent by the author on the design and drawing of the boilers submitted herewith and partly on knowledge acquired during 5 years' experience as an engineer of machine design. Fewer parts and the absence of riveted joints on the welded boiler reduce the labor of the engineering department and other related departments. The drafting is reduced materially by both the factors mentioned as fewer and simpler parts to draw take less time and the design and detailing of the rivet spacing in the riveted joints takes up a good percentage of the time required to design a riveted boiler. By comparison, the design of a welded joint is simple when undertaken by an engineer versed in welded design.

A comparison of the labor and material costs (including freight) between the two boilers shows a difference of 10.2% in favor of the boiler of welded construction.

Only direct labor is included in the labor cost of boilers. The labor cost of the riveted boiler is based on actual rates (as known to the author) paid to perform the operations required.

The labor cost of the welded boiler is based on comparable operations performed on the riveted boiler where operations were similar. Where operations vary and no direct comparison was available, the labor cost was estimated by the author and is substantially correct. In many cases it was based on similar work performed on other comparable types of welded equipment such as large welded tanks.

The labor cost is 7.4% greater for the welded boiler than for the riveted boiler. This is offset however, by a saving of 16.4% in the material cost.

The quality of workmanship specified, especially in connection with the welding of the welded boiler, is of the highest and most costly. The extra annealing layers R and R^1 (See Fig. 5), add approximately 33% to the cost of welding.

The cost of these boilers is based on building both on a production basis. The cost of the first welded boilers probably would exceed the cost shown in this paper, due to lack of facilities for positioning this particular shaped construction for welding and established standard shop procedures. When the construction of both boilers is performed on the same basis with equal facilities for each class of construction, the author feels the cost shown in this paper will be representative.

Gross Savings, General Efficiency and Economy.—In attempting to show the gross savings accruing to industry through the general adoption of the design described and the increased service life, efficiency, general economy and social advantage to mankind it would provide, this author must admit he has failed. The only advantage he has been able to show and substantiate is first cost. He requested information relative to cost of maintenance of riveted boilers on which to base some comparative cost figures but failed to elicit any information of value.

Even if the author had the maintenance cost of riveted boilers, the only comparisons which could be made would be based on theoretical values for the savings and advantages of the welded boiler and not capable of being substantiated due to the lack of time the design, to be eligible for entry in this contest, can be in existence. Figures showing these savings and advantages and capable of being substantiated, must be gathered over a period of years for a number of boilers and represent a general average and any other method would be highly theoretical and not in accordance with the rules of this award program.

However, without being able to substantiate any of these claims except for first cost, we do know that the service life of the fusion welded boiler is substantially longer and the efficiency and economy (due to no leaks and better circulation) is also much improved. The gross savings to industry and social advantages to mankind in the form of lower freight rates

or higher dividends, or both, and greater safety to engine crews due to this higher efficiency and economy and lower first cost, has a definite value.

When permission was given by the Interstate Commerce Commission to build the first locomotive boiler to have all seams of fusion welded construction, it was stipulated the boiler must first be used in stationary service, subject to very frequent inspection of the welded seams. When and if it passed this preliminary period of service satisfactorily it could be placed in rail service, subject to removal of lagging and close inspection of welded seams at intervals of three months.

The boiler did pass the preliminary stationary service period successfully and was put in rail service and has been stripped of lagging and had the seams inspected for the third time and at no time were any leaks or defects found in the welded joints. The boiler has been in service approximately 1 year* including stationary and rail service. The railroad company operating the boiler has saved what it would have cost to keep the seams tight on a comparable riveted type boiler over this period.

Summary.—The author realizes the boiler submitted herewith may not be the very latest as far as design is concerned. The belly stays may be out of date and other minor details may be old fashioned but for purposes of comparing the two types of construction it should be entirely satisfactory. No claim to originality of welded design or application on the firebox sheets of welded joints (except those joints where the firebox sheets are welded to the mud ring) is made by the author as the fusion welding of the joints in these sheets has been done for some years.

The "Pocket List of Railroad Officials" No. 172, issued for the 4th Quarter of 1937, gives a total of 51,013 steam locomotives in the United States and Canada as compared to 1155 of all other kinds on freight carrying roads. Thus, 97.74% of traffic is moved by steam power as compared to 2.26% by all other means. It is noted that most diesel, diesel-electric, gas and gas electric locomotives (203) are used in shifting service and that most electric locomotives on steam roads (534) are used in passenger and passenger terminal service, thus leaving practically all the real freight hauling, revenue producing service to the steam locomotive. Much has been said and written about the various types of locomotives other than steam but up to the present time it still reigns supreme as a mover of revenue-producing freight and will continue to do so.

* At time paper was written.

Chapter IV—Changing from Riveted to Welded Construction in Manufacture of Freight Cars

By Clyde B. Faverty,
Chief engineer, The Ryan Car Co., Chicago, Ill.

In the following paper I have purposely not included a specific problem in freight car construction, but have confined this paper to a general discussion of the many problems encountered in changing a freight car plant from the building of riveted construction to welded. I have attempted to point out the manner in which these problems were solved in our plant.

In the design and calculation portion of the paper, I have attempted to point out that a new approach to the design of the various details is possible with welded construction. Great economies can be made thereby and a better balanced design will result. The final design for welding may be entirely different than the riveted and will be stronger, lighter, and cheaper.

Obviously, the problems encountered in the redesigning of the riveted construction in other parts of a freight car will be very similar to those outlined. Because of the revolutionary nature of welded construction, the methods of shop procedure which I have described should be of considerable assistance in solving problems in this new field.

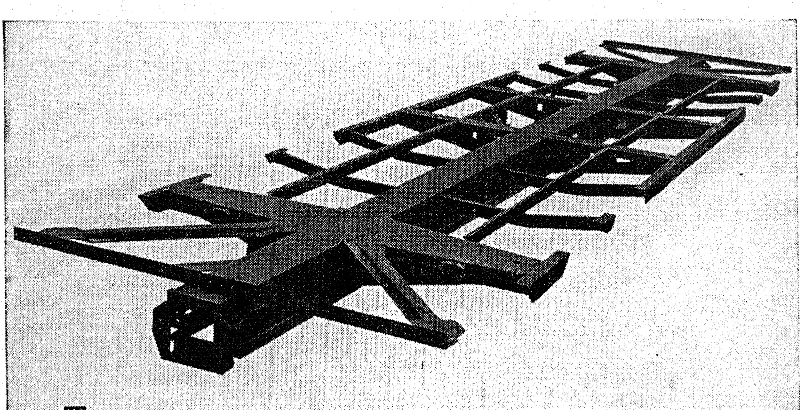


Fig. 1. Arc welded underframe for railroad freight car. 1000 lbs. lighter, 10% less costly than former riveted frame shown in Fig. 2.

I am submitting this paper, with supporting blue prints, calculations, and photographs, covering the design, construction, shop problems and their solution, in connection with the building of a lot of 2,600 all-welded underframes, (See Fig. 1), for box and auto cars for a Class A railroad in the United States. Underframes of this type in the past have been of

riveted construction, (See Fig. 2), and this is the first endeavor to build a large number of these underframes from an all-welded design.

This paper includes reference to the problems encountered in the design and building of these frames, a comparison of the riveted and welded designs, and the economies of the welded frame in service. An attempt has been made to explain as clearly as possible some of the problems that may be encountered in the establishment of welding to replace riveting in the building of freight car underframes. However, this experience might reasonably be applied to the building of the balance of the freight car body.

Identifying the Underframe of a Freight Car.—The underframe of a freight car is that portion of the car body that rests upon the trucks, from which the sides and ends are supported. It is that portion of the car between the flooring and the center plate of the trucks.

The function of the underframe is to distribute the lading load to the supporting reactions at the center plates and the car sides. The underframe serves to support the floor and tie the sides and ends together. It has sufficient reinforcements at the junctions with the sides to properly distribute the load at these points. It is arranged with supporting brackets for the air brake equipment and the foundation brake rigging. The underframe must also receive the brunt of the end shock, dissipating a portion of it within itself and delivering the balance to the car body and lading.

The center sill is the backbone of the underframe and consists of a continuous uniform section from coupler to coupler. The center sill serves to carry a portion of the lading load between the crossbearers and bolsters, to receive the end shock, and to transmit the pulling force of the locomotive throughout the train. The balance of the underframe consists of bolsters, crossbearers, stringers, side sill reinforcements, end sills, diagonal braces, and miscellaneous supports for equipment.

Origin of a Standard Design.—The design of underframe which was accepted as standard by the American Association of Railroads was developed at a conference of the railroad engineers together with the engineers representing the car building companies. This was an effort to obtain an economical design using a minimum of excess material.

Previous to the establishment of the A. A. R. standard design, underframes in service on the railroads of the United States were built from the experience of the master car builders of the various railroads. Obviously, they were all different, and in many cases considerably more weight was used in the design than the service required. There was no standard method of calculating the load distribution, and in most cases the underframes were excessively heavy.

When the A. A. R. Car Construction Committee and the car-builders' engineers met to discuss a standard design, a certain method of calculating the load distribution was agreed upon. From these calculations a satisfactory design was established. This design was arranged for the assembling of the various parts by riveting. The riveting equipment then in use played an important part in the selection of the design. The riveted design of underframe was, therefore, a compromise to suit the prevailing

methods of assembly rather than a design that would be ideally suited to the loads that it must carry. For several years nearly all box cars were built with this standard A. A. R. underframe, and many thousands of cars were constructed.

Fabrication and Production in a Freight Car Shop.—Underframes for freight cars are manufactured on a mass production basis. The materials of which they are constructed are, for the most part, the cheapest grades, and the quantities in which they are purchased tends to promote a low price. The fabrication of steel is done with such equipment as to make low costs of production possible. Parts are assembled through the use of special equipment suitably designed for rapid production.

In the fabricating end of the car shop business, men are trained through long experience to operate one machine with the greatest dispatch, and they are seldom required to do another operation. In the assembling of the car parts, men are selected for each operation who are familiar with that operation through long experience. The material is scheduled through the shop in such a manner as to produce a minimum of lost motion and to work into the finished assembly in accordance with a planned schedule. The plant equipment is laid out in such a manner as to produce a unidirectional flow of the material through the shop.

Orders for freight cars and car parts are generally placed in quantities of five hundred to a thousand, which means large duplication and repetition of operations, and a minimum of supervision is required.

The above indicates clearly that freight car manufacture is a low cost, mass production business, and based on the price per pound of the finished product, it is doubtful that the cost of any other equipment is as low.

The Status of Welding in the Freight Car Field in 1937.—Prior to the early part of 1937 it was a much debated question as to whether welding could be introduced into this field and money saved over the cost of riveting. It was the general opinion of people engaged in this business that welding was not amenable to assembling operations where the continuity of the assembling line was such that each operation was dependent upon another operation. It was not felt that welders had been trained to produce sufficient output to replace riveting. It was not generally believed that a uniform amount of welding could be done in a given time by welders. Some doubted that the welders could be assigned to a production line in the same manner as riveters. Freight cars are built to fairly close tolerances, and it was generally believed that the welding would distort the structure so that considerable straightening expense would be involved. It was evident that other problems would require solution, for instance:

(a) It would be necessary for fitters to work in close proximity to the welders.

(b) It would be necessary to protect fitters from the arc.

(c) The underframe would have to be securely fastened and rigidly held at the time the initial welding operations were being performed.

(d) It would not be advisable for welders to do any of the fitting work, as it would be likely to result in an unsteady hand. This would mean that fitters and welders must alternate in positions, which is a further change from established methods with fitters and riveters.

A study of the above conditions led many people to believe that welding could not be successfully applied to freight car underframe construction with a saving over riveted procedure.

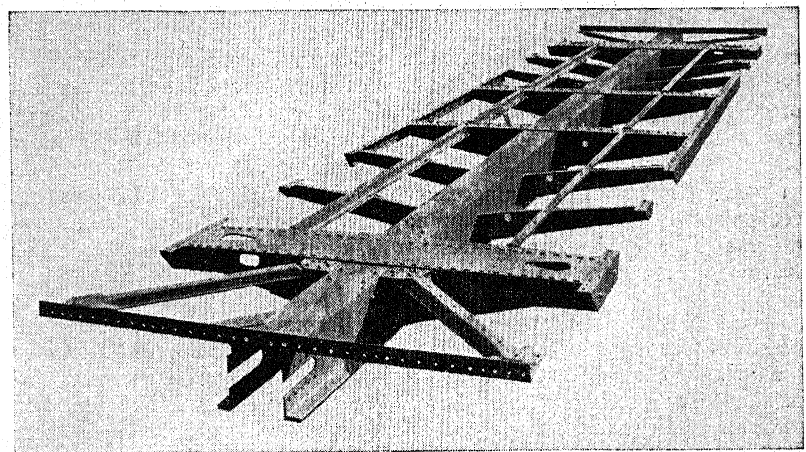


Fig. 2. Freight car underframe of riveted construction.

Welding Limitations in Freight Car Shops.—Manufacturing methods in car building plants will place certain limitations upon welding. Welding methods that are being followed in the construction of machinery cannot be duplicated in the freight car industry because costs will not permit. In machinery construction, scarfing or beveling of the edges of the plates to permit penetration through the full metal section is general practice. In most cases the metal sections on freight cars are not of sufficient thickness to make this requirement necessary, but in any case, the cost of beveling and scarfing would be prohibitive. In many cases, construction will only permit the welding of the joints from one side and information on the strength of the joints welded in this manner was not available. We decided that it would be necessary to make a great many test specimens, including joints welded from one side only and without copper backing strips, also to observe the extent of penetration with various openings, and to pull-test these specimens for strength. Considerable interesting information was accumulated from these tests which proved useful in the development of the final underframe design.

Welding in Unheated Buildings.—In car building plants, construction work is carried on in large, unheated steel buildings at outdoor temperatures. The question of the quenching effect of the cold steel adjacent to the weld was raised and it was thought that if welding operations were carried on at low temperatures the welds would be brittle. To prove

or disprove this point, a great many specimens of low-carbon steel and low alloy were cooled with dry ice to a temperature of minus 30°F. and welded. These specimens were welded from one side with a single bead so that subsequent beads would not anneal or normalize the original weld. At the same time, similar specimens were welded at room temperatures. Some of these specimens included thin sections welded directly to a heavy metal section where the maximum in chilling effect would result. After welding, they were then bent at the weld and the angle to which they could be bent before a fracture occurred was observed.

The result of these tests showed little difference in the angle to which the cold steel and the steel which was welded at room temperatures could be bent. The test specimens in alloy steel which were welded at a temperature of minus 30°F. showed slightly less angle of bend at the time of the initial fracture. It was concluded, insofar as the welded joint itself was concerned, that welding could be carried on in the existing car building plants without the necessity of heating the steel, but it was also recognized that the work performed by the operator is likely to be less satisfactory at cold temperatures. It is advisable to keep the operator warm by heating the location in which he is working.

The Normalizing of Welds.—It is impractical to normalize the welds on freight car underframes because of excessive costs, and therefore some thought must be given to the locked up stresses. These stresses can be alleviated to some extent by the welding procedure. It is the opinion of some engineers that the service loads will cause equalization of the stresses over a period of time, and that they will gradually adjust themselves. They also contend that stressing the weld to the elastic limit will equalize and reduce these locked up stresses. With this in mind we provided equipment to give every underframe a load test so that the principal load carrying members could be stressed 50% in excess of the maximum service load. Welded freight cars now in service seem to bear out the fact that locked-up stresses in car construction are not serious and that progressive fatigue cracks do not develop at the welds. However, this experience is limited and several years of service with a great number of designs will be necessary to bear out these points.

Studies of Welded Underframe Designs to Replace Riveted.—We made preliminary studies of welded designs that would replace riveted in various parts of the underframe and a comparison of the cost of manufacture was considered. In the fabrication and forming of the individual parts the welded designs had some advantages over the riveted, for instance:

(a) Pressings could be eliminated.

(b) The cost of handling and punching the steel was greatly reduced.

(c) Machine and die set up charges were often eliminated.

A study of the assembling methods which seemed most appropriate for the welded designs indicated very little similarity to past practices

with riveted construction. The question of the amount of welding that should be used had to be considered. In many cases if the entire joint was welded from both sides a strength factor would be developed in excess of that necessary to carry the loads, and also several times greater than riveted construction would be in a similar location. In some of the preliminary welded designs which were studied, if the entire joint was to be welded continuously the cost of this work would exceed the cost of riveting. In some cases an intermittent weld is all that is necessary to carry the loads.

Many designs were discarded because the amount of welding made them uneconomical. Later studies developed suitable construction for the various parts of the underframe with a reduction in the number of joints and the amount of welding, and that they could be assembled more economically than the riveted which they replaced. It was quite apparent from these early studies that welding would allow a greater versatility of design than riveting.

For the purpose of acquiring a unit construction it was agreed that a greater amount of welding should be used at any point in the structure than was necessary to equal the strength of the rivets. It was felt that welded designs must be stronger, lighter, and cheaper, than the riveted in order to make them attractive to the trade.

Bolster Construction for Underframes.—The following pages show comparisons of three methods of bolster construction for underframes:

(1) Standard A. A. R. riveted bolster.

(2) A commonly accepted method of replacing riveted construction with welded construction.

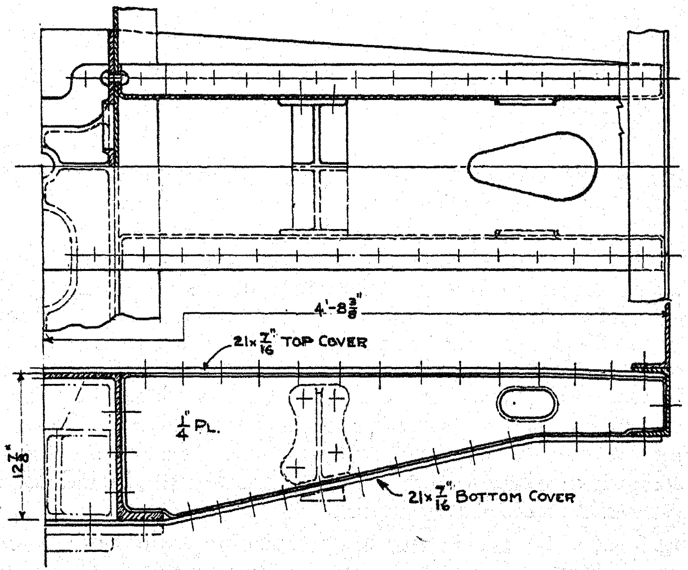


Fig. 3. Standard riveted bolster.

(3) The final bolster design which proved to be the strongest, lightest, and most economical.

The bolster shown in Fig. 3 consists of a 21 x 7/16" top cover plate, a 21 x 7/16" bottom cover plate, and four ¼" pressed pans separating them. The strength of the pressed pans is not included in the calculations when determining the resisting moment of the joint at the center sill. This is due to the fact that the flange of the pan is not stiff enough to develop the strength of the rivets connecting it to the sill. The top and bottom cover plates only are included when calculating the strength at this joint. The resistance of this construction against end shock is also limited to the strength of the two plates.

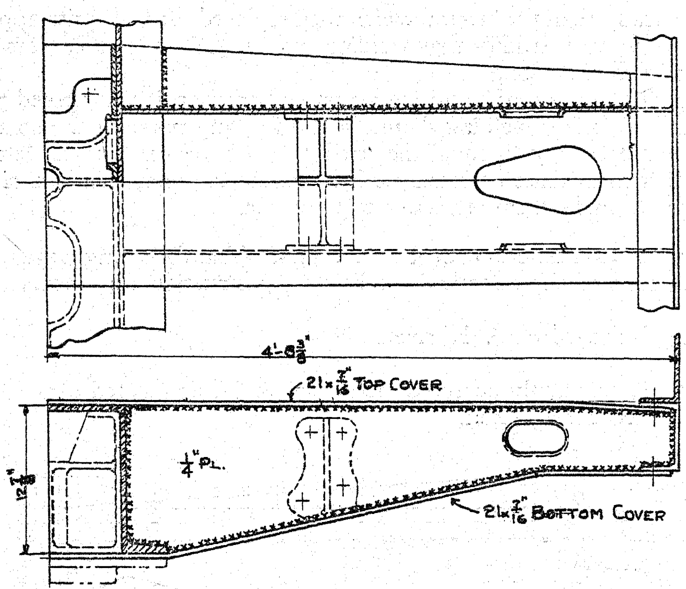


Fig. 4. Commonly accepted method of replacing riveted construction with welded construction.

The construction shown in Fig. 4 is a commonly accepted method of replacing riveted with welded construction. It merely substitutes similar members for those used in the riveted construction but eliminates the flanges. In this case, the attachment of the web plates to the center sill is improved, and the strength of these joints can be included with the top and bottom cover plates. The strength of the web plates and their joints with the center sills can also be included with the cover plates when considering the strength of the bolster against end shock. It is evident that this design involves considerable welding, and our studies indicated that the cost would exceed that of riveting.

Fig. 5 shows the final bolster design which proved to be the strongest, lightest and most economical. The welded construction takes the fullest

advantage of welding to gain the maximum in strength at the least cost. It is a considerable departure from the preceding and has the following advantages:

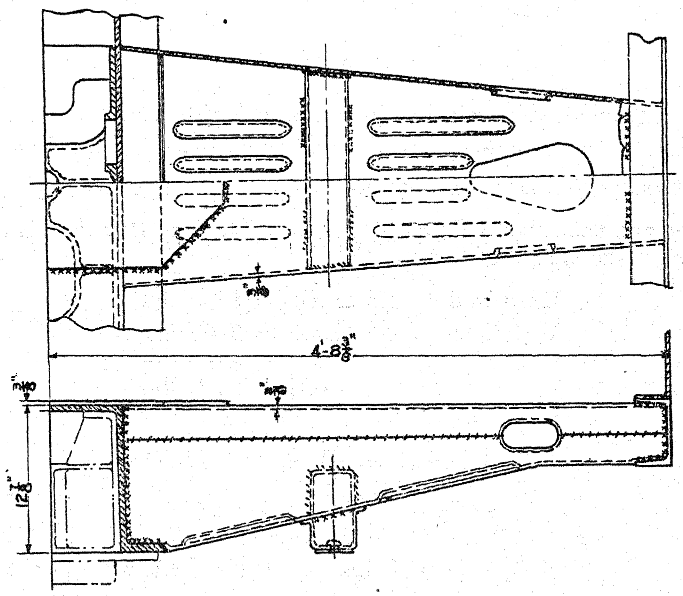


Fig. 5. The final bolster design which proved strongest, lightest and most economical.

(1) A minimum of welding is involved. There are only four horizontal seam welds.

(2) The web plates are located at the extreme edges of the top and bottom plates where their strength will be greatest against end shock.

(3) The bolster is tapered from center sill to side sill to develop a uniform stress with a minimum of material.

(4) The full strength of the web plate is developed at the joint with the center sill.

(5) The bottom plate of the bolster is corrugated because this portion is in compression and the corrugations provide the desired stiffness.

(6) This construction is an improvement from a manufacturing standpoint because the bolster halves can be assembled together as a sub-assembly independent of the main underframe. This permits welding of

the horizontal seam where the bolster may be revolved to bring the weld in a downhand position.

Calculations.—The following calculations cover the final welded design and show a uniform stress from center sill to side sill.

50-TON CAR

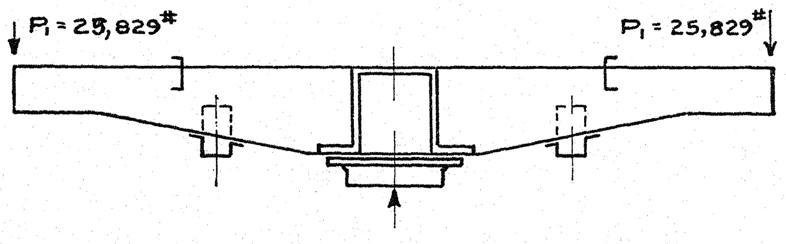
A.A.R. method of calculating load at end of bolster.

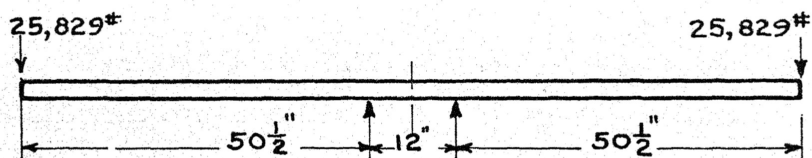
Load on end of bolster $P = P_1 + P_2 + P_3 - P_4$. Where P_1 = half of load on crossbearer from center sill $= \frac{R_3}{2}$ P_2 = half of load on side sill (lading and floor plank) P_3 = ¼ weight of car body (less dead load on center sill and weight of floor plank).

Dead load on center sill	=	8300 lbs.
Weight of floor plank	=	2190 lbs.
Total		10,490 lbs.

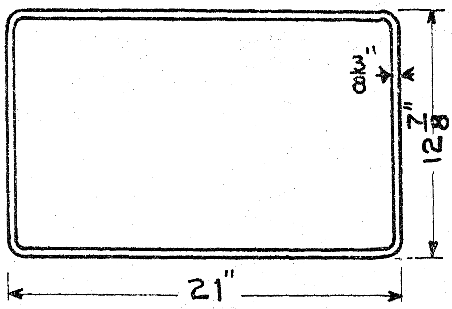
P_4 = ½ of uplift on end sill $= \frac{R_1}{2}$

$P_1 = 109.44 \times 185.64 \div 2 =$		10,185 lbs.
$P_2 = 571.4 \times 20.25 =$		11,571 lbs.
$P_3 = ¼\ (28{,}000 \text{ lbs.} - 10{,}490 \text{ lbs.}) =$		4,378 lbs.
		26,107 lbs.
$P_4 = 2{,}999 \times 185.64 + 2 =$		278 lbs.
$P_1 =$		25,829 lbs.





Bending moment at center sill = 25,829 lbs. x $50\frac{1}{2}$ = 1,304,364 lbs.



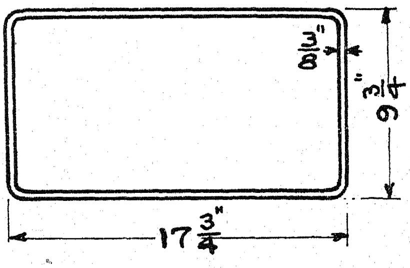
$$\text{Sec. Mod.} = \frac{701.3}{6.44} = 109 \text{ in.}^3$$

Sec.	Area	d	Ad²	I
2—20¼x⅜	15.19	6.25	593.3	
2—12x⅜				108

$$\text{Total I} = \frac{108.}{701.3}$$

$$\text{Stress} = \frac{1,304,364 \text{ in. lbs.}}{109 \text{ in.}^3} = 11,970 \text{ lbs. per sq. in.}$$

Bolster section at side bearing. (2 ft. 1 in. from center)



Section	Area	d	Ad²	I
2—17x⅜	12.75	4.69	281	
2— 9x⅜	6.75	———		46

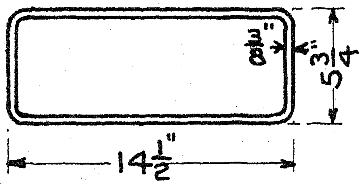
$$\text{Total I} = \frac{46}{327}$$

$$\text{Section modulus} = \frac{327}{4.875} = 67.1 \text{ in.}^3$$

Bending moment = 25,829 lbs. × ($56\frac{1}{2}$ in. — 25 in.) = 814,000 in. lbs.

Stress = 814,000 in. lbs. ÷ 67.1 = 12,130 lbs. per sq. in.

Bolster section 13¼ in. from side sill.



Section	Area	d	Ad^2	I
2—13¾x⅜	10.3	2.69	74.5	
2—5x⅜	3.75	———		7.8

$$\text{Total I} = \frac{7.8}{82.3}$$

$$\text{Section modulus} = \frac{82.3}{2.875} = 28.6 \text{ in.}^3$$

Bending moment = 25.829 lbs. $\times$ 13¼ in. = 342,000 in. lbs.
Stress = 342,000 $\div$ 28.6 = 11,960 lbs. per sq. in.

Manufacturing Procedure.—After a suitable welded design was established, the methods of manufacture were mapped out. Consideration was given to the following:

(1) The Sequence For Assembling the Various Parts of the Underframe.—The underframe was divided into the various units that could be made up into sub-assemblies. These consisted of bolster halves with side bearings and side bearing stiffeners, crossbearer halves, center sills complete with center fillers and draft lugs, strikers, and cylinder supports.

The bolsters were made up of two pressed pans. The lower pan had a body side bearing reinforcement welded into place, and the two pans assembled in pairs to the proper height gauges and welded along the horizontal seam. The body side bearings were placed in the proper location on these bolsters, in pairs, and gauged for the proper height. The bolsters were then ready to be assembled on the underframes with the body side bearings in their proper location.

The crossbearers were made up of top and bottom angles with spaced web plates. They were assembled in revolvable jigs. The joint between the web plates and the angle was welded from both sides in a jig backed up with a copper strip. The crossbearer halves were then assembled together by skip welding and gauged for length and fit. Any minor corrections were made at this time by grinding, chipping, or burning.

The stringers and cylinder supports were pre-assembled in a like manner with all welding done in a downhand position.

These sub-assemblies were then brought together along with cross-ties, side sill reinforcements, diagonal braces, and end sills. This much of the underframe was securely welded together and then the stringers and miscellaneous equipment brackets were applied.

(2) How Fitters and Welders Can Work in Assembling These Parts Without Interference.—In all cases we found that it was necessary to provide duplicate jigs so that the fitters could be assembling a set of parts while the welders were working on another set that had been assembled previously.

(3) The Effect of Shrinking of the Weld and Drawing the Members Out of Their Proper Position.—Jigs must be made sufficiently strong to resist the contraction of the weld metal. When either the sub-assembly or the complete underframe is removed from the jigs there is an adjustment in the position of the parts which is due to the contracting of the welds. An allowance must be made in the construction of the jigs to accommodate this movement so that the finished part will be to the proper dimensions.

(4) Gauging the Miscellaneous Equipment Brackets.—In the riveted construction, all miscellaneous equipment brackets are located by holes for rivets or bolts. It was obvious that no such holes should be provided in the welded design. However, clamps, fixtures, and gauges were made to support and secure these parts until they could be attached by welding.

(5) The Number of Positions Required for Rapid Assembly.—It was obvious that sufficient men could not be placed upon the underframe in one position to complete it, and, therefore, several positions were provided. It was decided that all welding must be done downhand, which is the position in which the most satisfactory welding can be done at the lowest cost. This had a bearing on the number of positions used. It also meant that the frame must be revolved during assembly.

The initial fitting of the underframe was done with the frame members upside down on the face of the jig. This was decided upon because it is more important that the top surface of the underframe be held to gauge. After all the welding that could be done in this downhand position had been completed, the underframe was turned over and securely fastened in a second jig in the right-side-up position. All welding was then completed on the top side of the frame that could be done in downhand position.

The underframe was then removed from the stationary jigs and placed on a pair of shop trucks and moved along to the next position where stringers and miscellaneous equipment brackets were located. These parts were tack-welded to the frame. The underframe was then moved to a position where it was set up in trunnions to be revolved so that the balance of the welding was in a downhand position. When the underframe left the trunnion position it was completely welded and ready to be O.K.'d by the car shop and railroad inspectors. In the O.K. position, any unsatisfactory welds or insufficient welds were corrected and the underframe checked with gauges for all principal dimensions. If it should be

necessary to straighten any of the underframe members, it could be done at this time.

The underframe was then passed to the cleaning and painting shop and, after sufficient time was allowed for the paint to dry, it was loaded and blocked on railroad flat cars for shipment to the railroad shops.

The Selection of Welders.—It is quite evident that it is advisable to have the welders perform the same task repeatedly so that they will become accustomed to that operation and will make better time. From the manner in which freight cars are assembled and the quantities in which these orders are placed, it is possible to divide the welding up so that each man will have his particular task to do. Production welding of this nature is somewhat new, and the general run of welders available are not accustomed to welding in a progressive system. The majority of experienced welders are pressure vessel men where quality rather than quantity is the predominating requirement.

Contrary to our experience with fitters and riveters in freight car shops, we were not able to select suitable welders from applications based on years of experience. It was necessary to hire and test a great many welders before a sufficient number was found to fulfill our production requirements. It was not unusual for welders with ten to twelve years experience to fail to produce sufficient welding to meet the production schedule, and, in many cases, men with little experience would more than qualify. It seems that the will to work and the ability to make the least unnecessary moves in performing their task is more important in this type of work than many years of experience. In this class of welding, all of the work is done downhand, and in most cases the size of rod and amperage to be used will not change throughout the day.

Of recent years the trade schools have been graduating many young men with approximately 30 hours of welding training. Many of these men with a little additional experience can fit into car shop welding positions and perform their task along with more experienced men.

The initial test that was given all welders was to weld a few samples of plates together with a single bead. These plates were approximately 3/16" thick and were not beveled. They were spaced slightly and the welder was given an opportunity to become accustomed to the machine. After the samples were made, they were inspected for uniformity of weld and the manner in which the weld was started and finished off. The samples were then bent and broken to determine the extent of the penetration. The manner in which the welds were made was considered in determining eligibility. These tests were conducted by a thoroughly experienced welder who had had considerable experience in handling of men.

Miscellaneous Shop Problems.—The difficulties encountered in the production of these underframes consisted of the education of fabricating shop forces to the importance of holding overall dimensions uniform and to gauge, the importance of properly locating copes, the proper gauging of the shear blanks upon the dies, and the necessity for allowing hot pressed shapes to cool without warping.

In the assembling of the frames it is extremely important to provide

spacing of the parts to allow for shrinking of the weld. This is important to increase the penetration and depth of the weld and to minimize the effects of initial stresses. A weld laid over a joint where the two plates are closely fitted together will be shallow and the stress set up from the shrinking of the weld may result in the development of a crack.

The selection of the welding rod for work in various locations is important. Considerable of the welds in freight car construction will be fillet welds and a fillet rod will produce the best appearance. Wherever there is an opening it is generally necessary to use a filler rod that will not run freely when melted. In many cases, the proper welding procedure will require the use of a filler rod to start the weld and to finish off with a good fillet rod. Where an opening exists and it can be satisfactorily backed up with a copper backing strip, the entire weld may be made with a fillet rod in order to produce the best appearance.

We believed that it was quite important and therefore trained our welders to properly finish off a weld by eliminating the crater. We found, from test experience, in breaking many hundred test specimens, that the failure usually occurred in the crater first. It is therefore important that the starting and finishing of the weld be done at a point where stresses are not concentrated, or a point where a fatigue crack will not originate. A study of the welding procedure from these angles is extremely important. In many cases where one member is to be joined to another, the weld can be started around a corner and carried the full length and finished around the corner. Where additional welding is to be done in another position, the end of the weld can be lapped to reinforce it.

Supervision of Welders During Production.—When production was being started, very close supervision and instruction of the welders was maintained. Instruction and supervision was necessary even with experienced men to assure their doing their job in a satisfactory and uniform manner. After the men became accustomed to their task through constant repetition, the necessity for instruction became less and it was then only necessary to check each finished underframe for quality of work. It was not difficult to go back to the welder who was performing a certain operation if it was found that the welding at a certain point in the underframe was not up to the standard requirement. It was very encouraging to find that after a number of frames had been built the welders became thoroughly accustomed to their job and the welds were finished off uniformly and with machine-like appearance.

Economies of Welded Underframes in Service.—Welding the underframe of a freight car unites the entire under part of the car body into a homogeneous structure. It eliminates the concentration of stresses at rivet holes, and permits the full strength of the metal section at the joint. Most important of all, it eliminates the lap, and seals all joints against corrosion. The welded underframe will, therefore, result in a stronger car body with less weaving of the structure and will be longer-lived.

The welded construction around the strikers and bolster center-fillers will entirely eliminate the trouble from loose rivets in these members. It is well known that the buffer portion of the striking casting which receives

the shock from the coupler horn, after the draft gear has become worn, is the first part to fail. In the welded construction this part of the striker is a separate unit from the front draft lugs and the coupler carrier. It may be renewed independently of these other parts.

The welded underframe design saves nearly 1,000 pounds in weight over the riveted. Authorities agree that the cost of handling dead weight on a freight car is $18.00 per ton, per year. This welded design will, therefore, save $9.00 per underframe, per year, in addition to the savings in the original construction cost, and also a saving in maintenance cost because of the elimination of joints.

The saving in the original cost is nearly 10 per cent of the former cost of riveted construction, which, if adopted as standard, would result in a saving of approximately $1,000,000 per year to the railroads of this country.

Future Possibilities of Welding in This Field.—Some idea of the future possibilities of welding in the freight car field may be gained from the following:

There are approximately 100,000 new freight cars built per year. With an economical design suitable for welding, there would be approximately 1,200 lineal feet of welding per car. This represents 480,000 man days, or approximately a year's work for 2,000 welders. If you add to this the amount of welding that can be properly applied in the repairing of freight cars, it would appear that an estimate of one year's work for 4,000 welders would be conservative.

This field will be opened to welding through the development of proper designs and the acceptance of welding as a substitute for riveting by the railroad engineers.

Chapter V—Arc Welded Steel Roof for Freight Cars

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The object of this paper is to discuss an all-steel arc welded roof for use in the railway industry on box and other types of house cars, to supplant the all-steel riveted type of roof construction so extensively used today in the manufacture and repair of freight equipment. It is frequently necessary to replace the roofs of existing freight cars, and the practicability, economy and advantages of the arc welded roof design hereinafter described will be shown to be justifiable over the conventional riveted roof construction.

Only two instances of welded roof applications are known, and they are believed to be the first and only proposals whereby arc welding has been applied as an aid to freight car roof construction.

The first of these was applied to a large railroad-owned-and-operated refrigerator car, built new, in September of 1935. This construction consisted of a number of 16-gauge unformed steel sheets of stock material extending crosswise of car from eave to eave, butted together over, and arc welded to, several roof transverse members or carlines, a section through which is illustrated by Fig. 1. In addition to this

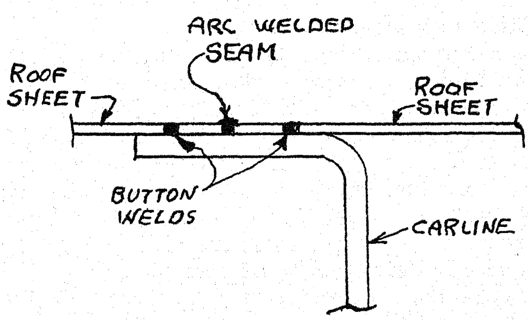


Fig. 1. One method by which arc welding has been applied to freight car roof construction.

arc welded seam or joint, numerous ⅜″ diameter holes were punched in the sheets at intervals of 3″ and button welds made through these holes as shown. The roof sheets were secured at the eaves and to the car ends with rivets. This type of construction did compare favorably with the all-steel riveted type of roof, but the fabrication of the sheets to accommodate the button welds and the numerous tack welds that were necessary before the actual welding operation was performed in order to avoid warpage, were obvious disadvantages.

The second case involved a railroad box car on which press-formed roof sheets were applied in a manner similar to that described above, with sheets welded at seams and riveted at eaves and at car ends, but

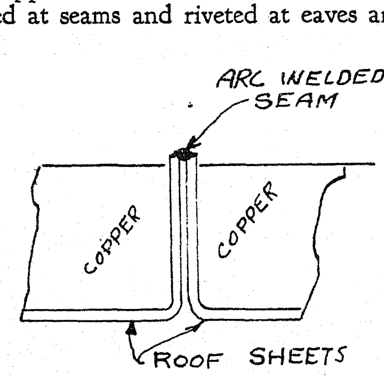


Fig. 2. Second method by which arc welding has been applied to freight car roof construction.

with an arc welded seam or joint as illustrated in Fig 2. No transverse members or carlines were used with this construction. Heavy copper plates as shown in Fig. 2 were utilized to alleviate the heat during process of welding. This manner of arc welding proved to be slow and was objectionable from the standpoint of production output. Furthermore, the elimination of transverse members or carlines obviously weakened the roof structure and was too questionable a departure from standard freight car construction.

A recent inspection of the first type of partially arc welded roof on the railroad refrigerator car mentioned showed the arc welds to be in perfect condition after almost three years.

There was described in the February 15th, 1936, issue of a railway publication, an all-steel spot welded dust proof refrigerator car built by the Pullman Standard Car Manufacturing Company, involving the utilization of sheets 0.05″ in thickness. A considerable decrease in ice meltage is claimed for this car due to the tightness of welded construction. The proposed arc welded construction of roof described in this paper can also claim all the advantages of this spot-welded Pullman refrigerator car, and furthermore is readily applicable to refrigerator and other types of house cars.

The arc welded roof we propose has not actually been built, but since only conventional welding procedure is necessary, it is believed that there are no practical obstacles to its construction.

The accompanying drawing, Fig. 3, illustrates the complete arc welded roof design proposed, and shows it adapted to a common 40′ box car. Detail description of this welded roof is as follows:

Roof sheets are 16-gauge black annealed mild steel, size 72″ x 120″, the 120″ dimension extending across top of car, there being no seam at the ridge of the roof. In order to stiffen these members and provide for expansion and other longitudinal movements, they are shown with a pressed profile between transverse supports. The arc welded seams between the sheets occur over the centers of the "A" shaped transverse

members or carlines, where the sheets are curved to conform to their profile. All sheets except those at the ends have this profile, these being different to join with the steel ends of the car. The "W" structural shape used at the eaves of this type of car acts as a welded support, and is parallel by a slight change in profile to limit warpage during welding and provide for sideward movement within the roof.

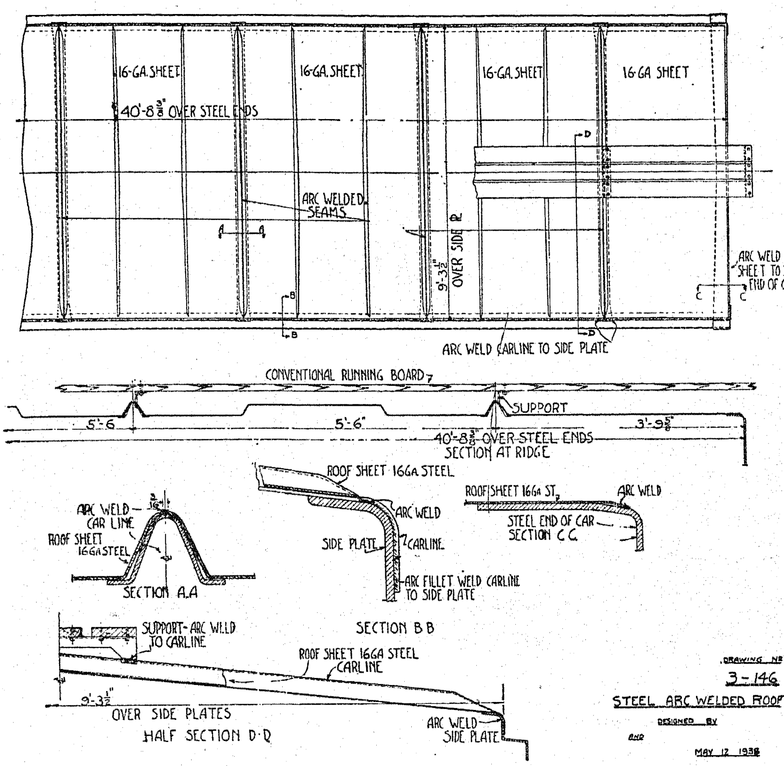


Fig. 3. New arc welded roof design applied to 40-foot box car.

An important point in the design of this roof is the "A" shaped carline and butt welded joint between roof sheets. The "A" shaped member is necessarily press formed, and serves the same purpose as other carlines used as transverse bracing in house car roofs.

It is an established fact that arc welding of thin sheets is not especially easy because of the possibility of burning through or of concentrating heat and causing warpage. The design shown by Section "A-A" in Fig. 3 provides a backing-up to conduct heat away from the roof sheets, and a means of making a butt joint between them. An actual test of welding on this type of member developed a property that was not at first obvious. It was noted that the usual warpage parallel to the sheets, and the tendency for the two sheets to separate in two planes, was not present.

Tacking previous to welding was not necessary because the adjoining sheets pulled inward and downward to the "A" carline with the first welding. The result was fusion to the carline and fusion between sheets as shown in photograph Fig. 4, which shows a section through the weld.

The carlines extend from one side of car to the other, lapping down over the "W" shapes at the eaves as shown by half section "D-D" in Fig. 3. This is the only variation from downhand welding on the roof. The lap acts as a tie to brace the roof and sides of the car, and necessitates a special design of the roof sheets at the junctions of transverse and eave seams.

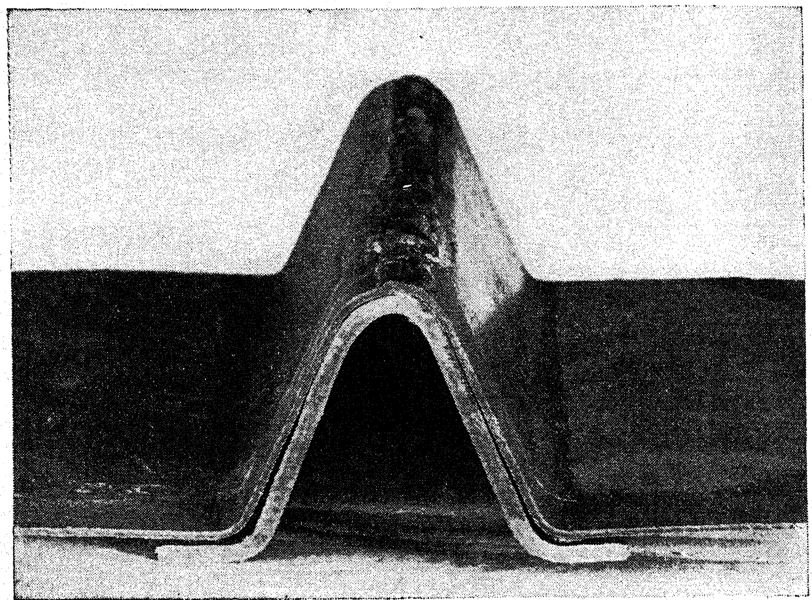


Fig. 4. Section through weld, showing fusion to carline and roof sheets.

Manner of fastening running boards to roof is, as shown in Fig. 3, by means of steel supports arc welded to carlines, and while wooden running boards are preferred by the Association of American Railroads at the present time, metal running boards are being looked upon with favor by many of the larger carriers, and their use is desirable with these welded roofs.

Arc welded refrigerator car hatch frames of high tensile steel are being used regularly in the railway industry, and it is suggested here that corrosion-resisting roof sheets be utilized around the ice hatches of refrigerator car arc welded roofs to reduce maintenance cost brought about by salt corrosion.

The table which follows shows the economic comparison of a riveted as compared with an arc welded roof. The figures for the former are actual time study figures for the assembly and riveting of a ready-formed roof of which the purchase price was known. These figures were

obtained in the assembly of these roofs in lots of 200. The figure for prefabrication of the arc welded roof was obtained by deducting 10% for punching holes from the cost of the riveted roof previous to assembly and installation.

TABLE SHOWING COMPARISON OF COSTS FOR RIVETED AND ARC WELDED STEEL ROOFS FOR RAILWAY HOUSE CARS

RIVETED ROOF		ARC WELDED ROOF	
Fabrication:		**Fabrication:**	
Shearing of sheets		Shearing of sheets	
Forming and bending		Forming and bending	
Punching of holes		Forming carlines and running board supports	
Forming carlines and running board supports			
TOTAL COST OF 20-YEAR ROOF FOR 40′ BOX CAR:	$146.00	TOTAL COST OF 20-YEAR ROOF FOR 40′ BOX CAR ($146.00) MINUS 10% FOR PUNCHING HOLES:	$131.40
Assembling:		**Assembling:**	
Setting in place	$ 0.81	Setting in place	$ 0.81
Reaming and fitting up all holes	3.47	Labor: Arc welding 178 lin. ft. 3 Hrs. 45 Min. @ 87¢ per hr.	3.27
Driving 554 rivets	4.10	Cost of welding rod: Welder deposits $2\frac{1}{4}$ lbs. per hr. $3\frac{3}{4}$ hrs. at $2\frac{1}{4}$ lbs. per hour equals 8.43 lbs. of shielded arc electrode. 8.43 lbs. electrode @ $10\frac{1}{2}$¢ costs	.89
Cost of rivets: 196 $\frac{1}{2}$"x$\frac{3}{8}$" in B.H. or 22.6 lbs. 358 $\frac{3}{8}$"x$\frac{3}{8}$" B.H. or 31 lbs. Total, 53.6 rivets @ 15¢	8.04		
GRAND TOTAL COST OF RIVETED ROOF:	$162.42	GRAND TOTAL COST OF ARC WELDED ROOF:	$136.27

Saving for arc welded roof over riveted job.....................$26.15, or 16%

Gross Savings to Industry.—The Official Railway Equipment Register for 1937 listing equipment on railroads of the United States, Canada, and Mexico, is authority for the following figures. From these figures a gross savings to the railroad industry is shown based on the $26.15 saving per roof by arc welded construction previously given. The actual

saving for more complicated roofs could probably be shown to be greater than this.

	Refrigerator	Other House Cars
Refrigerator and other house cars on 21 of 740 railroads in United States and Canada	25,844	572,211
Refrigerator cars operated by 11 of 25 privately owned car companies in United States and Canada	107,711	
Total number of house cars		707,766
90% of 707,766 cars equipped with arc welded roofs instead of riveted roofs		635,189
Gross saving at $26.15 per roof		$16,610,202

It must be remembered that the above mentioned gross saving to the railroad industry is based alone on the cost of application, and does not include the enormous sums paid out by the carriers in damage claims each year for contamination of lading due to infiltration of moisture, dust and other foreign matter.

A memorandum dated July 20th, 1937, issued by the Association of American Railroads, Operating and Maintenance Department, Freight Claim Division 59-E. Van Buren Street, Chicago, Ill., Committee on Prevention of Loss and Damage, gave one of the primary causes of damage to freight as defective equipment. This was elaborated upon primarily as the defects of car construction which permit cinders, rain, and dust to pass through roofs and sides of cars onto the lading. Loose ridge caps, roof caps, and bolts in the roof caused these leaks. Tightening of these

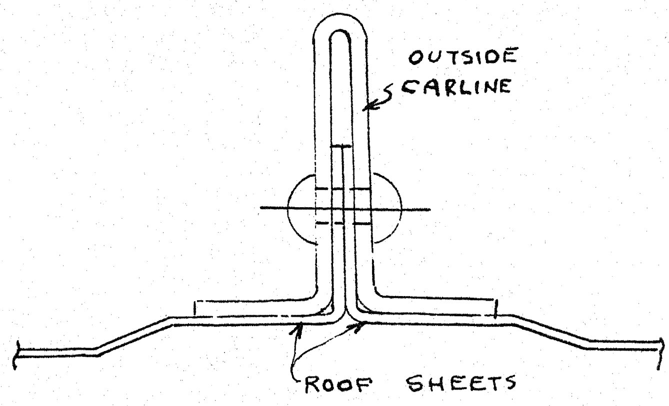


Fig. 5. Riveted joint at roof sheet looks tight. However, the vacuum produced when car is in motion, draws foreign matter through the opening. (See Fig. 6.)

parts and use of plastic materials at open joints has been found to be a necessary repair. One major carrier paid out the enormous sum of $34,000 in damage claims for year of 1937 caused by cinders, rain and dust.

While riveted roofs do overcome in a large measure this infiltration of dust, cinders, and moisture, they are not as leakproof as is desirable.

Fig. 5 illustrates a typical riveted roof sheet joint used in the construction of an all-steel riveted roof, and from all appearances, this is a tight joint. However, from observation it has been found that such ideal conditions do not actually exist, and the ventilation provided at ends of every carline as shown in Fig. 6 creates a vacuum action when car is in motion and causes foreign matter to be drawn into car through small openings. Furthermore, it is obvious that rapid corrosion will ensue where there is a collection of moisture between two closely fitted metal surfaces. (See Fig. 6.)

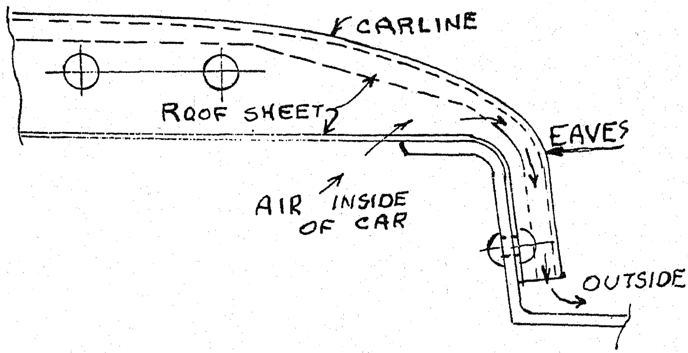


Fig. 6. Ventilation provided at ends of every carline creates a vacuum action when car is in motion.

The all-steel arc welded roof, herein described, will remain free from infiltration and corrosion of any kind throughout lifetime of car.

We believe that the method of construction herein described plus the extensive use of arc welding introduced in the fabrication of a steel arc welded roof, will eliminate any objection common to an all-steel riveted roof, and this, together with its lower cost of application, should formulate a most desirable product for railroad use.

Chapter VI—Design and Construction of Arc Welded Motor Rail-Car

By RALPH J. DION,
Arc welder, Bloedel, Stewart & Welch Ltd., Bloedel, B. C., Canada.

For years the operators of the lumbering industry on the Pacific coast, have been using small motor-driven rail-cars to convey men, freight and machinery to and from all points of their operations, in some cases over a hundred miles of railroad mainline, branch lines, and spurs.

Although lacking the facilities of a well equipped shop, we were able to design and build a number of very efficient motor rail-cars, (See Fig. 1), exactly suited to our company's particular requirements, at a substantial saving of cost, by the use of arc welding, over previous methods of construction.

The 3/8" x 6" channel iron chassis frame was laid out and all joints welded, including gussets, motor mounts, spring-slide shackle cleats, cross members and lugs for torque rod connections and equalizer bar, by two men, in one eight-hour day. Holes were drilled for deck-bolts, running boards, etc., before assembling. Channel iron was the only material purchased for the frame. Gussets, motor-mounts, lugs, etc.,

Fig. 1. Arc welded motor rail-car built at saving of $5,000.

were odd pieces of plate and short ends of strap iron from the scrap pile.

Had this frame been built by the alternative method—rivetting—it would have been necessary to drill, accurately, hundreds of holes for rivets. Heavier members would have been necessary to compensate for the weakening of all joints by rivet holes. Angle-iron cleats would have been necessary at all joints, requiring more material, more weight, and more labor. The actual joining of the parts by rivetting requires a gang of at least three men, for heating and driving rivets, backing

up, reaming or drifting holes. Considerable equipment is required also: air compressor, air hose, rivetting gun, dies, reamers, drills, etc. The same job would take several days for at least three men, and within a short time the rivets would wear slack in the holes by the constant weaving of the frame. Costly repairs and delay would result.

The only equipment required to build the welded frame was an arc welder, and a cutting torch. As the welded joints are much stronger than the parent metal of the frame itself, the welded frame will serve the life of the machine.

Journal boxes are generally of cast or malleable cast iron. Standard journal boxes were not suitable for this job, and in order to have had them made to our requirements it would have been necessary to have drawings made and sent to a foundry, at the nearest industrial center, hundreds of miles away.

Instead, we went to work with the cutting torch and arc welder. With some odds and ends of plate and scrap pipe, we laid out and welded together four steel journal boxes. The four journal boxes, with spring and tie-rod lugs, were laid out, cut and assembled by the arc welder in eight hours. The complete boxes, machined, cost less than the patterns alone for casting. They were much stronger and 30% lighter because they were of steel. There was no waiting or delay, and the weldings were right, since we built them ourselves to suit the job. We were able to use roller bearings in the journals at no extra cost, through the saving in cost of the journal boxes.

Torque tubes were made from 2½″ hydraulic pipe with gussets of ¼″ plate tack welded to each side, and welded to the journal boxes, and adjustable torque tube toggles were made up.

Spring slide shackles were used, and were readily made up by welding strap iron lugs to plate, torch-cut to required dimensions.

Axles were machined down from worn car axles.

It would have cost $36 each to have sprockets cast of steel. Four were required. We made these by torch-cutting ¾″ plate to required diameters, and welding to hubs, cut from ends of broken shafting. The teeth were laid out by drilling and machining. Later we found that it was necessary to alter the ratio between transmission and drive sprockets; in this case, we torch-cut the sprockets, to be changed, away from the hub, re-cut the teeth to give the desired ratio, then welded on to the hubs again, (approximately 50% less cost).

The two break beams complete with break-heads were built by a welder in one eight-hour day. The beams were made from 2″ hydraulic pipe, wishbone ½″ x 2″ band iron, brace rod ⅝″ round stock, and break heads of ¼″ scrap plate; all torch-cut and welded. The brace rods were bent and heated before welding into holes cut in the beams, so as to shrink tight. Brake rods were readily made by drilling and arc welding ⅜″ x 1½″ band-iron ends to ⅝″ rod.

These rail cars must be built so as to run at all transmission speeds, in either direction. This we accomplished by means of two crown gears, running on roller bearings on a jack shaft in constant mesh with the crown gear pinion. To the crown gear bearing hubs, we welded the plate discs on which are bolted the crown gears; as shown in section, Fig. 2. Changing direction of travel is accomplished by means of a

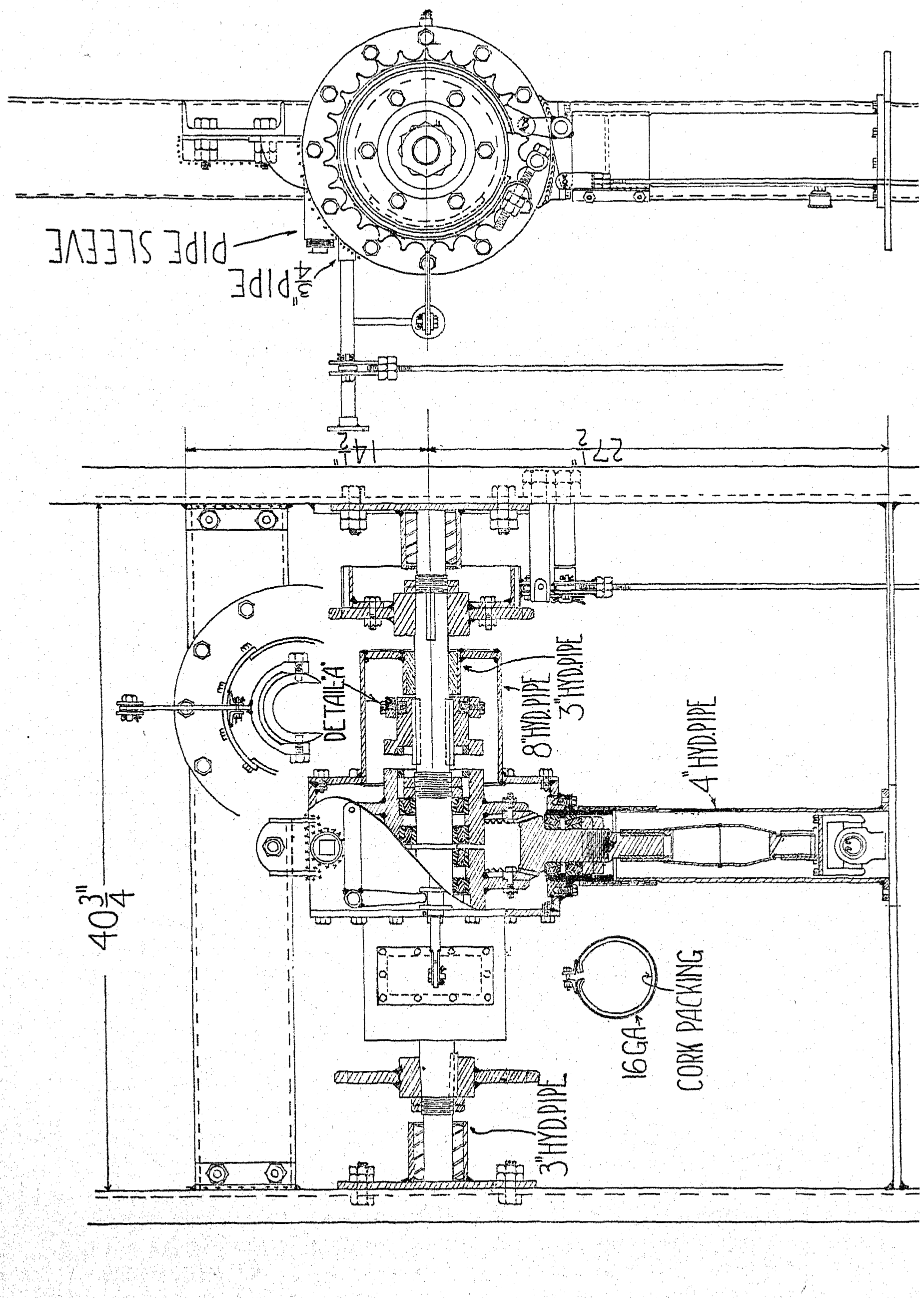


Fig. 2. Details of reversing transmission of arc welded rail-car.

dog-clutch, cut in the hub of either crown gear. The operating dog-clutch sleeves are keyed sliding fits on the jack shaft, and are linked together. When the reversing crown gear is engaged, the go-ahead is disengaged. Shifting is accomplished by means of pivoting collar-yolks, to which are arc welded operating levers.

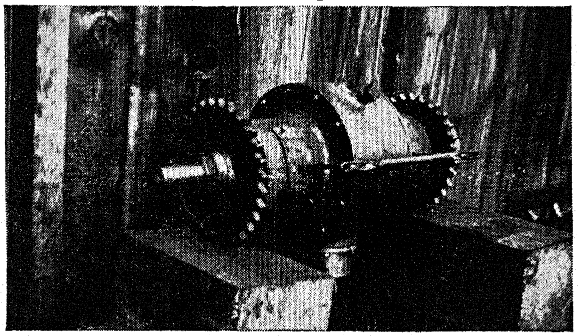


Fig. 3. Housing for reversing transmission of rail-car.

The housings for this assembly, as shown in Fig. 3, were made by welding together short lengths of scrap pipe, on to collars, torch-cut from $\frac{3}{8}''$ plate. Mild steel pipe sleeves were welded in for oil filler and drain, and supporting lugs welded on. These weldings were made in four hours, at a fraction of the cost of patterns alone for castings. The weldings are easier to machine, because they are of mild steel, and easier to handle because they are much lighter in weight; and being of steel they won't break. Jack shaft end bearings were readily made, simply by arc welding a piece of pipe on to a piece of mild steel plate, torch-cut to size required.

On a motor-driven rail-car of this size, the Department of Railway Inspection requires automatic air-operated brakes, to install which would cost approximately $800 for pump, receivers, equalizer, distributor, piping, gauges, etc., besides labor to install. So we drew some sketches with soapstone on a handy piece of sheet steel and so devised a mechanical brake power take-off, as in section, Fig. 4, perhaps not superior to automatic air, but at any rate, with the help of our electric welding machine, it was worth trying, and wouldn't cost a great deal to build even if the inspectors turned it down.

We made up a hub and disc by arc welding. Two friction band levers pivot on pins, which were welded to one side of this disc, the hub of which was pressed and keyed on to one of the axles. Alongside this operating lever disc is a drum, assembled from pipe and mild steel plate by arc welding, having a bronze bushing free on the axle, and on the side of this drum, next the friction lever disc, is welded a friction flange of pipe. A cone-bored sliding fits on the axle, operated by a hand lever bell-crank, and operating yolk and collar, engages the friction. A chain or cable from the drum connects to the braking system; this produces a smoothly operating power brake, similar in

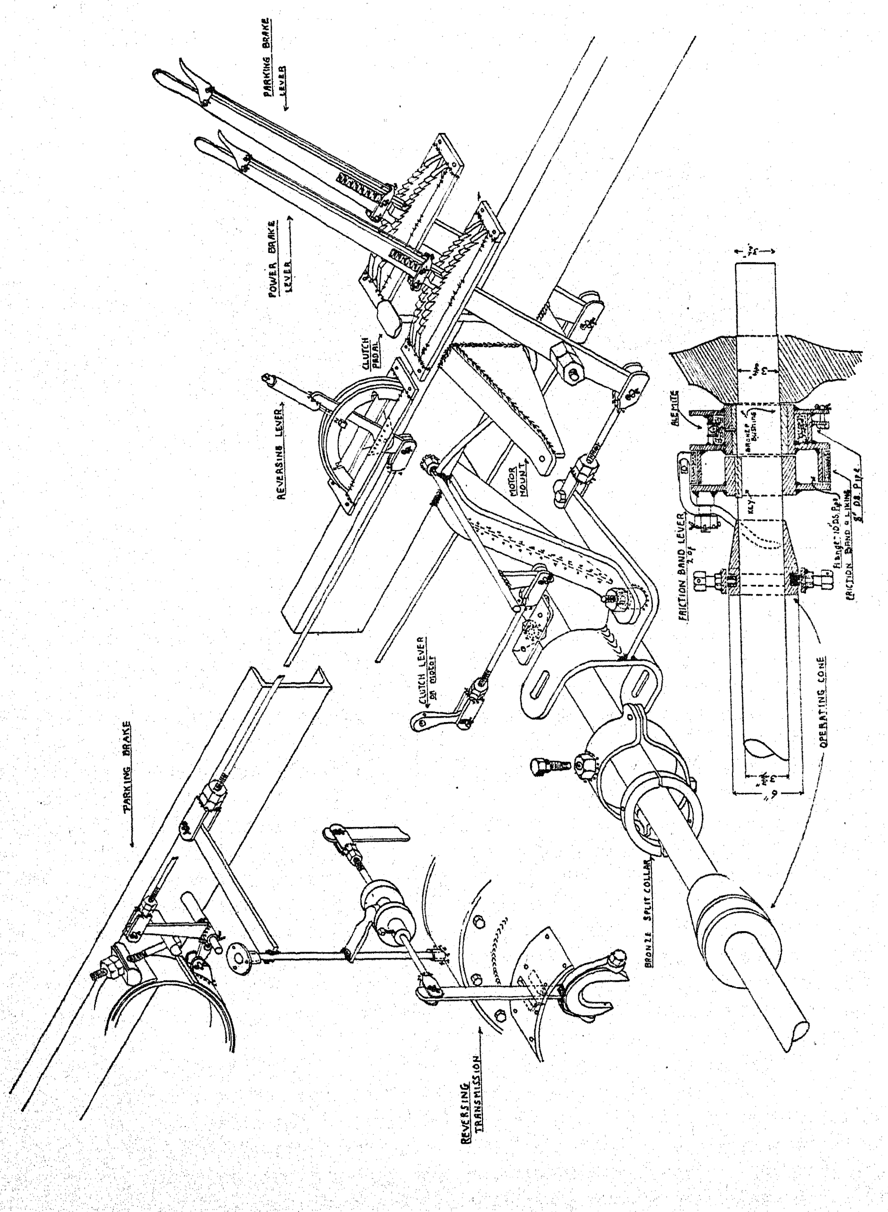


Fig. 4. Arc welded rail-car—power take-off assembly for main brake.

performance to air brakes. The railroad inspector was well pleased with this device, which eliminated well over 90% of the cost of the braking system. Here again arc welding was a major factor in effecting a considerable saving in the cost of this machine.

The controls, quadrants, links, bell-cranks, etc., were made easily and simply, as shown in the sketch, Fig. 4, by one man, the welder. Had all the links, devices, quadrants, etc., been made by alternative, or more primitive methods—such as forging, or casting—the controls alone would have amounted to a considerably larger item on the cost sheet.

The elevation, Fig. 5, shows the construction of the cab. The angle-iron frame was completely assembled and welded in 12 hours, the welder requiring help at intervals in assembling. Then 16-gauge sheet steel was tack-welded on the inside to the frame. Outside seams were lapped and arc welded. Bolting-down lugs were drilled, then arc welded to the angle-iron sills of the frame. Thus the cab, when completed, was electrically fused into one solid unit at a fraction of what it would cost to join the various sections by any other method.

Draw-bar heads were later added for use in moving a box car, or a few skeleton cars, about the yards. These were of similar arc welded construction, sturdy, yet light of weight, and inexpensive and quickly made.

Although the major factors in building these rail cars were low cost, utmost strength to withstand severe abuse in continuous uninterrupted service, and speedy construction, the appearance compares very favorably with similar machines built by other methods, and costing much more.

Previously, this writer's employers had a similar type rail-car, of the same general dimensions, built in their shops here. Arc welded construction was, however, scorned, and rivets or bolts were used to join members. Housings, journal boxes, torque members, etc., were castings. Brackets were castings or forgings. That machine, according to this company's records, cost $7500 to build, a makeshift cab of planking having been added later and the average maintenance cost of the car was approximately $2000 a year, over 7 years.

We have since built 4 motor rail-cars, using arc welded design throughout. Their total cost to build averaged $1500, approximately $5000 less than the car built by the former method. Thus, the executives have been able to feel more inclined to let the shop fit these cars for greater comfort and convenience to the operators, and to the men who ride on them daily, as passengers, to and from their jobs.

These cars are in constant service; some of them on two 8-hour shifts per day, seven days per week. One of them has run over 200,000 miles, and has worn out one motor and several drive shaft universals. It has needed no other repair. One left the rails at high speed with a heavy load, but was back on the job again the next day, having suffered only slight damage. No welded joints have failed. Another has suffered collision with a string of skeleton cars, but the end of the cab was only slightly damaged. It was straightened within a few hours. There were no weld failures.

The advantages of arc welded construction, apart from low initial

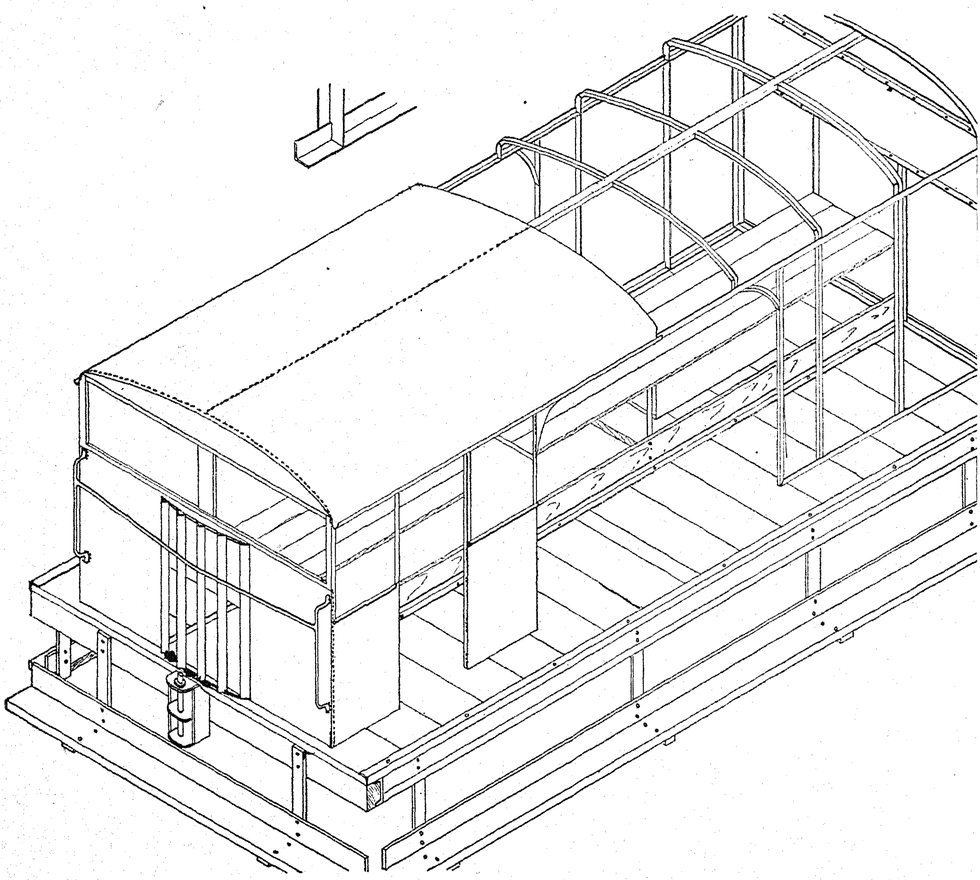


Fig. 5. Arc welded rail-car—details of cab.

cost of the product, are numerous. Its products are comparatively free from the necessity for costly repairs, or replacements, through failure. Thus, the inconvenience caused by delays or shutdowns is avoided. They are stronger, yet lighter in weight. Therefore, less motive power, and consequently less fuel, are required for their operation; or a greater load may be carried with the same, or even less fuel consumption.

No extensive engineering training or drafting ability is necessary for the average welder, or mechanic, to construct machines or parts of machinery, by this method of simply fusing together the parts to be joined.

Drawings for welded designs are less complicated to make and to read. Very often no drawings, other than rough sketches, are needed. No drawings were used in the construction of these rail-cars. The accompanying sketches were the first mechanical drawings ever attempted by the writer.

Although costing much less to build than a similar machine of previous design, these cars present a very pleasing appearance. And

because they cost much less, the builders were able to spend more time in finishing, painting, etc. The employees, who ride daily on these cars, unconsciously take pride in working for a concern which provides a more comfortable means for their transportation.

The railway inspectors have recommended our design and construction of these arc welded rail-cars to other operators in the industry, with the result that officials of several other concerns have come to examine them. Some have sent their shop foreman to take notes.

The rugged strength, economy and dependability of arc welded construction, together with very pleasing appearance of the welded product, have pointed a way to the operators of this industry to still greater savings, through its greater adoption in the construction of other machines. Parts which they once had to send away for, which caused huge losses through delay, are quickly replaced right here in their own shops. This results in less loss through costly tie-ups, therefore cheaper production, and greater profits, to both employers and employees.

Chapter VII—Welded Open-Frame, or Vierendeel Girders, Designed as Main Strength Members of Railway Coaching Stock

By J. D. Watson,
Design engineer, the Madras & Southern Mahratta Railway Company, Ltd., Park Town, Madras, India.

In orthodox railway coach construction in India a steel underframe is employed, on which a wooden structure is built, which forms the body of the coach. The body which is of considerable weight contributes nothing to the strength of the vehicle, and conversely the underframe has to be strong enough to support the body without undue deflection. As depth is limited, this is a matter of some difficulty and use has to be made of tie bars to obtain the necessary stiffness, an arrangement which cannot be considered to be ideal structurally.

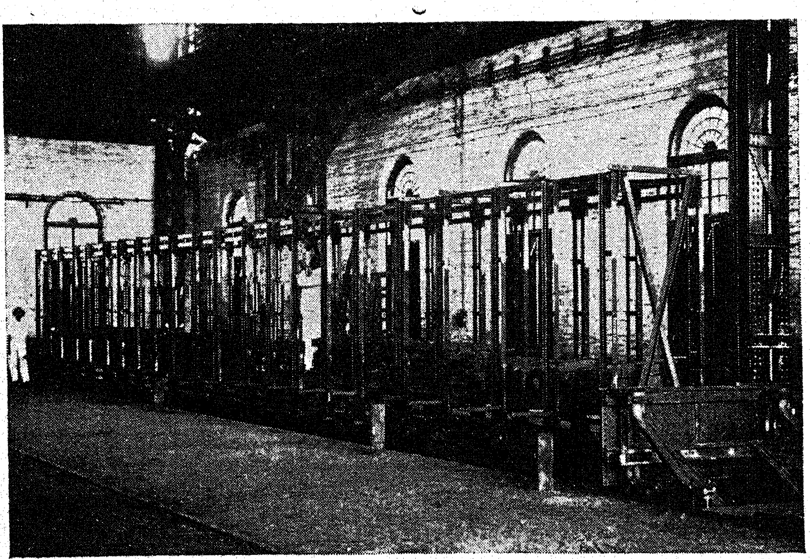


Fig. 1. Vierendeel girder frame member of coach set up for testing.

Recently engineers have realized that the orthodox conception of railway coaching stock is fundamentally wrong. It is considered that the body of the coach itself must be designed as a girder and that no heavy underframe is necessary. A very considerable saving of weight is possible by design on this assumption and this saving can be enhanced by the use of modern materials such as high tensile steel.

Accounts of all-metal light-weight rolling stock, of which a large number have recently appeared in the technical press, do not reveal that the design of such vehicles has received the attention it deserves. Analysis of published designs discloses a tendency to adhere to an underframe, containing the main strength members, on which a light body structure is built. The writer claims that it is only by designing the structure as a whole that the full benefit of light-weight welded construction can be realized, and suggests that the methods of stress analysis, as ordinarily applied to bridge design, can profitably be employed in designing frames for railway rolling stock, and in particular, passenger coaches.

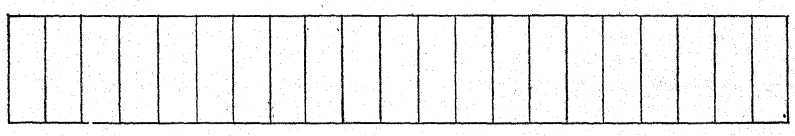
Two assumptions can be made when designing a coach by this method:

(1) That the sides of the coach act as girders and are braced by the floor and roof.

(2) That the roof and floor act as top and bottom boom members and the sides of the coach act as web members.

The first assumption is the simplest and will be discussed here.

The side of a coach is a rectangle. This in turn is perforated by smaller rectangles, i.e., doors and windows. If the side of the coach is to be designed as a girder, it is obvious that the usual form of triangulated girder is ruled out as the inclined web members would block the spaces intended for doors and windows. Only one type of girder is suitable—i.e., the "open frame" or "Vierendeel" girder, which consists of a top and bottom boom with a series of verticals joining them together, thus:



This type of girder depends for its strength on the stiffness of its component members and the rigidity of the joints connecting them together. It is particularly suited to welded steel construction.

Design of Open-Frame Girders.—In a paper published in the Journal of the Institution of Civil Engineers, London, for June, 1937, Mr. G. A. Gough gives a theoretical analysis of the open frame girder. This analysis was employed for designing an open frame girder, two of which have been built and tested in the carriage shops, Madras and Southern Mahratta Railway, Madras, India. The general layout of the experimental girder is shown in the drawing, Fig. 2. The panel lengths have been adjusted to accommodate standard doors and windows as used on Indian railways.

The experimental girders were designed for and built of mild steel to a permissible stress of 9 tons per sq. in. (20,000 lbs. per sq. in.). The design load was taken to be 21 tons (47,000 lbs.) per coach or 10.5 tons (23,500 lbs.) per girder acting vertically. The girders were designed to take horizontal draw-bar or buffing forces equal to 18 tons

(40,000 lbs.) or 9.0 tons (20,000 lbs.) per girder. The weight of the two girders as designed was 3.5 tons (7,840 lbs.).

Test of Girders Under Design Loads.—The girders were erected for testing as shown in the photograph, Fig. 1, and drawing, Fig. 3, and were tested as follows:

(a) The girders were first tested under a static load of 21 tons (47,000 lbs.). Stresses were measured with the Whitmore strain gauge in a very large number of positions throughout the girders. The highest measured stress was 7.8 tons per sq. in. (17,400 lbs. per sq. in.) in top boom panel 4-5. The highest observed stress in a vertical member was 6.70 tons per sq. in. (15,000 lbs. per sq. in.) in V.5.

(b) A horizontal load of 9 tons (20,000 lbs.) was then applied to the bottom boom of each girder, the load of 21 tons (47,000 lbs.) being left undisturbed. The highest observed stress was 9.5 tons per sq. in. (21,200 lbs. per sq. in.) in bottom boom member 4-5. The highest observed stress in a vertical member was 8.3 tons per sq. in. (18,600 lbs. per sq. in.).

Consideration of these stresses showed that panel 4-5 was by far the highest stressed panel. Excluding this panel, the highest observed stress in boom members was 6.3 tons per sq. in. (14,100 lbs. per sq. in.). It was therefore decided to strengthen panel 4-5 by welding on extra plates before carrying out the second part of the test program.

The method of strengthening panel 4-5 is shown in Fig. 2. Before strengthening, the load of 21 tons (47,000 lbs.) was removed. After strengthening was completed, fresh zero readings were taken with the Whitmore strain gauges and the girders were again loaded with 21 tons (47,000 lbs.) static load.

Strain-gauge readings were taken in all boom panels except 4-5 in this test. Panel 4-5 was omitted as it was considered that the amount of strengthening done on this panel was excessive and stress measurements would be of little interest. The highest observed stress in a boom member was 7.3 tons per sq. in. (16,400 lbs. per sq. in.) in top boom member 8-9. The stress in this panel was not measured in the first series of the tests and although within the permissible range, is considerably in excess of the calculated stress. The highest observed stresses in verticals occurred in V_5 and V_6 and amounted to 7.0 tons per sq. in. (15,700 lbs. per sq. in.). This corresponds closely with the previous observation of 6.7 tons per sq. in. (15,000 lbs. per sq. in.).

A horizontal load of 9.0 tons (20,000 lbs.) per girder was then applied to the bottom booms. The maximum observed stress in a boom member was 7.4 tons per sq. in. (16,600 lbs. per sq. in.) in top boom member 8-9. The maximum observed stress in a vertical rose to 8.8 tons per sq. in. (19,700 lbs. per sq. in.) in V_5. It is to be noted that the effect of applying a horizontal force to the bottom booms of the girders appears to be as follows:

(a) Increase of compressive stress in the bottom boom is less than would be expected, the calculations having been made on the assumption that the bottom boom would take all the horizontal force.

(b) The stresses in the verticals exceed the calculated values showing that they are transferring horizontal force to the top booms.

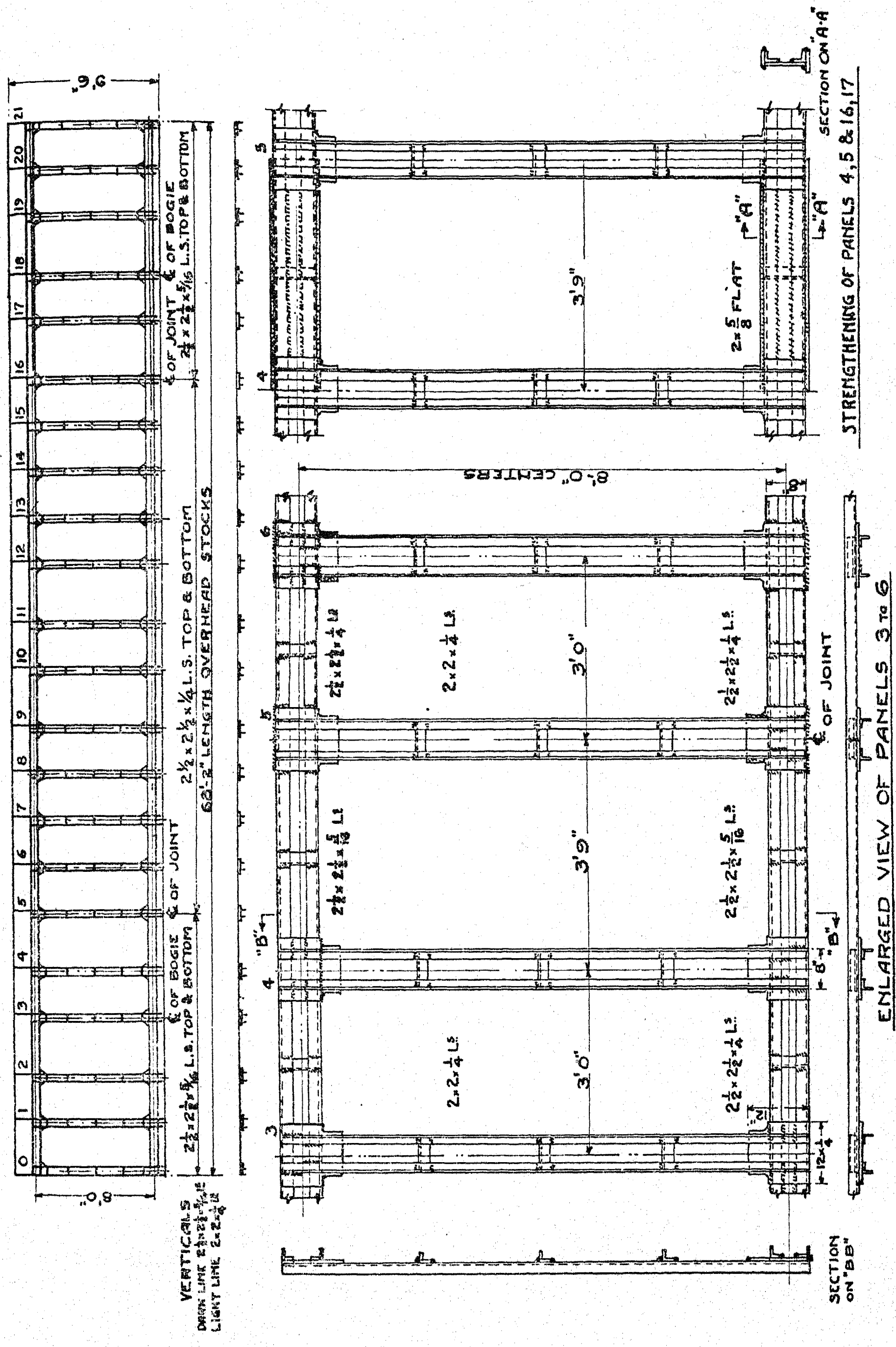


Fig. 2. General layout of the experimental Vierendeel coach frame girder.

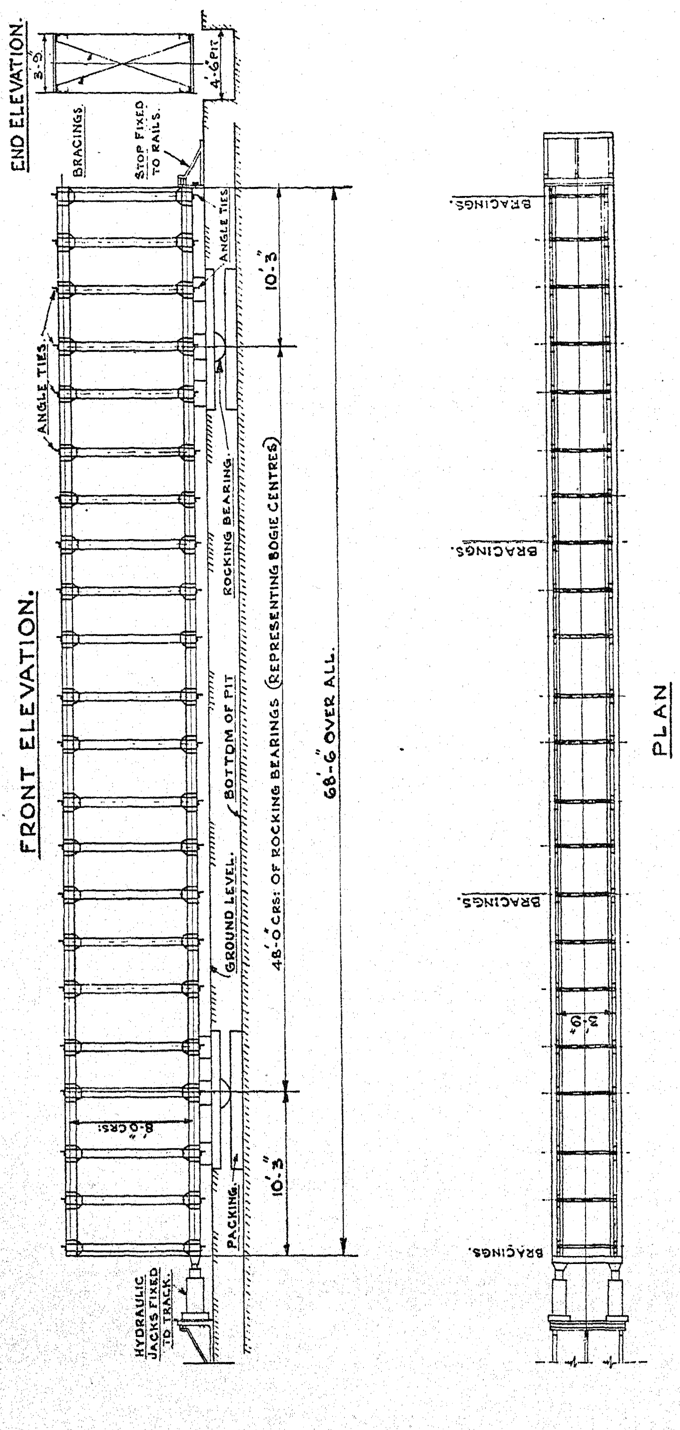


Fig. 3. General arrangement of the experimental girders erected for testing.

(c) The compressive stresses in the top boom exceed the calculated values showing that the top boom is taking a share of the compressive stress.

Conclusions from Tests Under Design Loads.—With the exception of panel 4-5 which is slightly overstressed, the design has justified itself. The calculated and observed stresses are not in precise agreement, but the maximum observed stresses fall within the permissible stress. The method of calculation is sufficiently accurate for design purposes.

Deflection Under Design Load.—The maximum deflection under the design load at the center of the girders was 1⅜″. In a subsequent design it may be desirable to introduce all or part of this amount into the girders as camber.

Test of Girders Under Loads in Excess of Design Loads.—To ascertain what reserve of strength there was in the girders, it was decided to carry on the tests with loads considerably in excess of the design load, but to stop short of destruction. The reason for this proviso was that it was intended finally to brace up the girders as a skeleton coach, mount them on bogies, fit draw-bar and buffer gear, and carry out shunting and possibly collision tests. The static load on the girders was increased by 50% to 31½ tons and two men standing on the girders at the center at each side imposed a pulsating vertical force on them by jumping up and down. After this test the welds were carefully examined but no failure or signs of incipient failure was observed. The horizontal force was then applied in steps of 4½ tons per girder, i.e., 9 tons, 13½ tons, 18 tons, 22½ tons, 27 tons, 31½ tons. Between each step the pulsating force was applied and the welds were examined, but no failure could be detected. The horizontal load was then increased to 34 tons per girder or 68 tons in all, at which load the buffer stops between which the girders were being tested began to fail and no increase of load could be applied.

Deflection Under 31½ Tons Static Load and Varying Horizontal Loads Up to 34 Tons per Girder.—The maximum deflection observed under 31½ tons static load was $1\frac{21}{32}$″. This increased under the horizontal load to $2\frac{1}{16}$″.

Stresses Under 31½ Ton Static and Various Horizontal Loads.—Stresses were measured in one position only on a few members. The highest observed stress was 10.33 tons per sq. in. (21,900 lbs. per sq. in.) under 31½ tons static and 31½ tons horizontal load per girder. This stress was measured in the middle of the top angle of bottom boom member 13-14, and may be compared with a calculated stress of 13.27 tons per sq. in. (29,600 lbs. per sq. in.). The stress is not likely to be a maximum. The force represented by the difference between these two figures appears to have been taken by the top boom.

Test to Destruction of Section of Boom.—A section of boom, 3′0″ long, was tested to destruction in the laboratory of the College of Engineering, Guindy. It failed as a strut at a load of 51.56 tons (115,500 lbs.). The welds were intact at the time of failure.

Conclusions from Tests Under Loads in Excess of Design Loads.—The girders have considerable reserve of strength and show a remarkable resistance to horizontal forces. The inference from this is that coaches built with side frames designed in this way can resist buffing and draw-bar effects without any special provision to take these forces. The deflection is perhaps on the high side but its effect can be neutralized by designing girders to a camber and its amount will be reduced by the added stiffness due to external and internal plating, of which no account has been taken in these experiments.

The welds stood up to this exacting test in an exemplary manner and no signs of failure could be detected by careful external examination.

The Advantages of Welded Fabrication.—At this stage it may be profitable to consider if the same result could have been obtained with rivetted fabrication. The strength of a Vierendeel struss depends entirely on the rigidity of the joints, and it is difficult to see how rivetted joints, of comparable stiffness, could have been designed. The legs of the small angles used could only take a single rivet, and the conclusion seems inevitable that rivetted trusses would have had to have been considerably heavier for equal strength. Each group of rivets would, in fact, be subject to a torque as well as direct stress and it is the writer's opinion that such rivets would inevitably work loose, resulting in a serious sag in the girders. The loss of section due to rivet holes, in the case of the small angles used, would also be considerable.

Saving Due to Welded Rigid-Frame Coach Construction Compared with Coaches Built on Underframes.—A trial design for a complete coach built on girders of this type has been made and is shown in Fig. 4. The estimated weight for a 5′6″ gauge III class coach seating 100 passengers is 29.1 tons (65,000 lbs.). The weight of a similar coach built on an underframe is 42 tons (94,000 lbs.). It is not claimed that the first cost of the light welded coach will be very much less than the orthodox type, in fact it may be more. The savings claimed for this type of construction are more fundamental and are based on the cost of hauling dead or unprofitable loads.

Pay-Load, Dead-Load Ratio.—Consider an ordinary passenger train. It consists of a locomotive and a series of passenger vehicles. In India, the locomotive, 5′6″ gauge, may weigh 160 tons and the passenger coaches 42 tons each. An express train may consist of a locomotive and seven coaches. The total dead load is, therefore, 454 tons. The pay load may consist of 400 passengers or 27 tons and possibly 3 tons of parcels or booked luggage = 30 tons in all. The pay-load dead-load ratio is therefore

$$\frac{30}{454} \text{ or } \frac{1}{15.1}$$

i.e. 15.1 tons of unpaying load has to be hauled for every ton of paying load.

Compare this with a similar train using the new type coach weighing 29 tons. A lighter type of express passenger engine, weighing 120

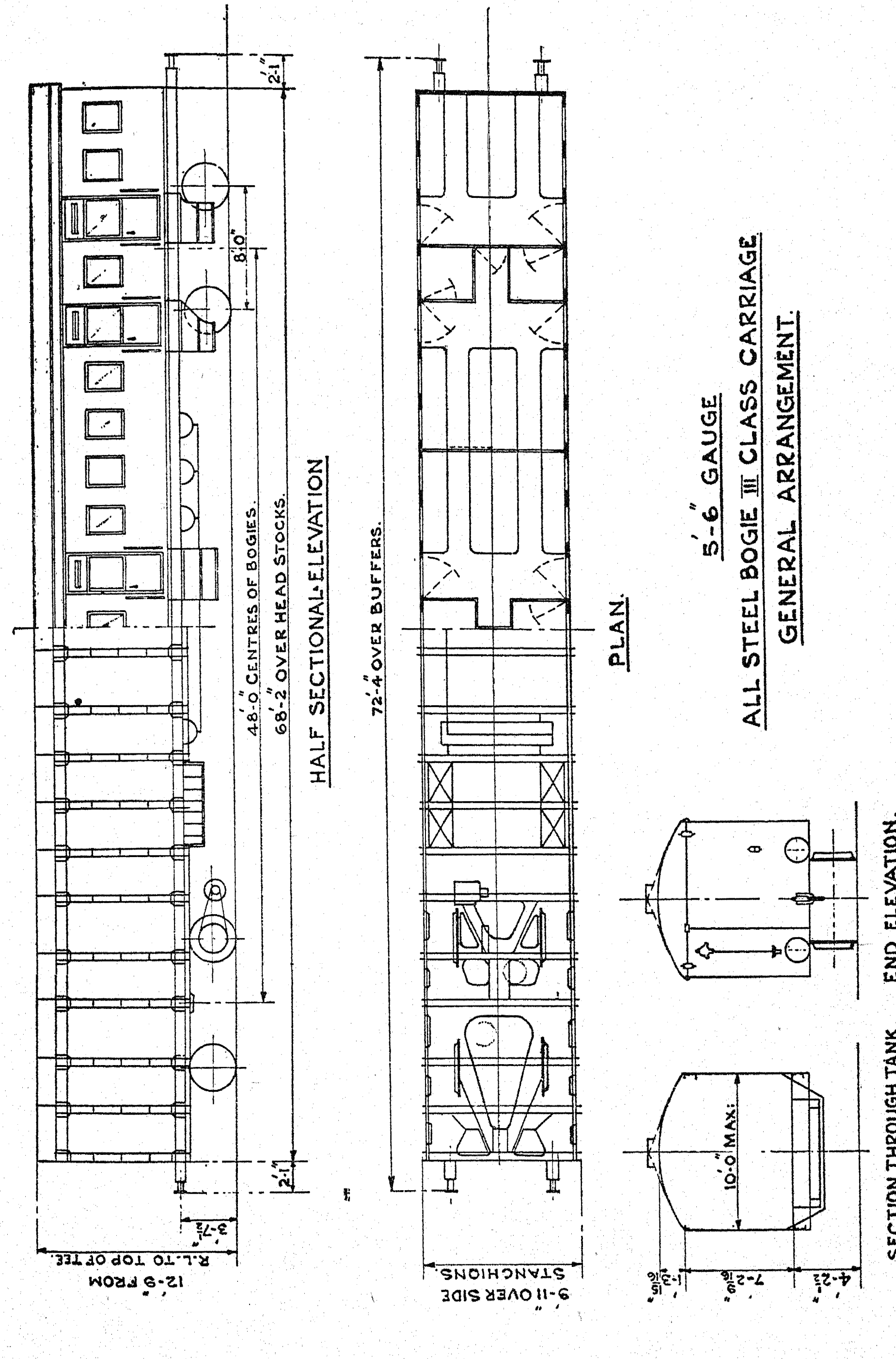


Fig. 4. Design of complete coach built on girders of the Vierendeel type.

tons could be used, and the total dead load drops to $29 \times 7 + 120 = 323$ tons. The pay load remains constant at 30 tons and the pay-load dead-load ratio has been improved to $\frac{1}{10.8}$.

Economies of Rigid-Frame Welded Passenger Coaching Stock.—Dr. Nichols of the B. B. & C. I. Railway has calculated that it costs Rs.135/, ($45.00), per ton per annum to haul passenger coaching stock under Indian conditions. In the case under consideration the dead load saving of 131 tons represents an annual saving of Rs.17,685/, ($5,895.00) per train. This is a very substantial annual sum and fully justifies adoption of rigid-frame welded construction.

General Conclusions.—"Vierendeel" girders, designed by the methods of rigid frame statics, are excellently adapted for use as the main strength members of railway coaching stock. Welded construction is necessary and economical as in no other way can rigid joints be made between the light sections that it is possible to employ.

Light coaches so designed can replace existing heavy stock at a very substantial operating saving for the railways adopting them. Alternatively, the saving of weight can be utilized for carrying air-conditioning plant for which there is a growing demand and for the use of which a supplemental charge can be made.

The author claims that the use of lighter rolling stock is the one fundamental economy left to railway administrations which remains comparatively speaking unexplored. He suggests that the savings to be anticipated, i.e., Rs.135/ ($45.00), per ton weight saved per annum, would warrant a considerable expenditure on research, and a vigorous replacement policy.

The author is indebted to Mr. C. G. Cordon, agent and general manager, Madras & Southern Mahratta Railway Co., Ltd., for permission to publish this paper.

Chapter VIII—Construction of a Light-Weight Passenger Coach Frame

By A. E. Katz,
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The car to be discussed is a light-weight single-vestibule passenger coach, (See floor-plan in Fig. 1.) designed primarily by the Canadian Pacific Railway Company, the method of construction being both arc welding and riveting. The coach material, as far as possible, was fabricated by the National Steel Car Corp. in Hamilton, Ont., Canada, and the coach was built by that firm. Many refinements in design were made by the building firm. This article will deal with some of the changes in design but mainly with our methods of construction, including the crude methods used on the first coach, and from that to the more or less finished technique employed on the latter coaches.

The welding required for this job fell into five classes; downhand welding of 3/8-inch rolled steel with 1/4-inch electrode; butt and fillet welding in all postions on 3/8-inch, 1/4-inch, and 3/16-inch hot rolled steel as well as welding steel castings of various thicknesses to the rolled steel, using 3/16-inch electrode; butt and fillet welding of light steel pressings 1/8-inch using 1/8-electrode; plug welding in all positions through 1/8-inch steel to 11-gauge plate using 1/8-inch electrode; butt welding 11-gauge sheets vertically and horizontally using 1/8-inch electrode.

Downhand welding with 1/4-inch electrodes was employed in welding the new American Association of Railroads light-weight welded center sill. This center sill was made up of two "Zee" bars welded together at the toes, 60% penetration was required and since the toes of the "Zee" bars were rolled with a chamfer, no trouble was encountered in getting this condition with a single-pass weld. Three 400-ampere machines of popular make were used on this job.

The underframe assembly called for butt and fillet welds in all positions. 3/16-inch electrodes were used. The machines available for the job were 200- and 300-ampere machines of popular make. These machines performed extraordinarily well under the circumstances since fit-up was poor in parts and a good deal of red lead was encountered at many joints.

The superstructure welding consisted mainly of tack welds, tacking the superstructure struts together. 3/16- and 1/8-inch electrodes and a 200-ampere machine were used. There, the flexibility of a machine with voltage and amperage control was an advantage with a low open-circuit voltage to facilitate tacking speed.

The sheathing was then applied, all welding, both plug and butt, being done with 1/8-electrode and overhead welds with 5/32-inch electrodes. Six 200-ampere welding machines were used on this section of the assembly. The welding was difficult to do and a high arc voltage was desirable owing to awkward positions and length of welding beads.

All miscellaneous welding was done by anyone of the operators free at the time.

The electrodes were chosen for their penetrative qualities, ease of handling, ductility of weld and freedom from slag inclusions, ease of deslagging, and flat bead characteristic. The standard S. A. E. tests for welding electrodes were made as well as tests simulating the actual working conditions. Electrodes finally chosen were a well known all-purpose, downhand type, $\frac{1}{4}$-inch in size, together with a vertical and overhead rod in $\frac{5}{32}$-inch, and $\frac{1}{8}$-inch sizes. The voltages and amperages used were practically the same as those recommended by the suppliers.

The Underframe.—The underframe was built up of steel shapes, pressings and castings welded and riveted.

The center sill of the car consists of 2 "Zee" bars, each 77 ft. $6\frac{1}{4}$ inches long welded together. Penetration required was 60 per cent and due to the chamfer on the underside of the sill, it would be impossible to get more than that amount of welding from that side. The "Zee" bars were set up in a center sill jig and wedged to the proper camber before welding. Three operators welded the sill in 60 minutes using 14 pounds of electrode. At the same time, fitters set up a second sill for welding on an adjacent jig. At first, two operators welded the sills but, due to unequal expansion, cracks occurred. The difficulty was overcome by using three operators.

The side sills, two per car, of riveted construction are each built up of an angle bar and "Zee" bar the same length as the center sill.

The bolsters, two per car, are all welded. (See Fig. 2). They were built up from steel pressings, shapes and scrap pieces. The pieces were assembled in a positioning jig which could be rotated to fillet weld all parts of the bolster in a downhand position. The placement of the bolster parts in the jig was such that the top plate of the bolster was concave when the jig was tight. After welding, on releasing the jig, the bolster became perfectly straight due to the stresses being self-relieved. Two operators assembled and welded the bolster in 10 hours and 30 minutes using 41 lbs. of $\frac{1}{4}$-inch electrode.

The remaining components of the underframe were the floor beams, 25 in number, of light channel members, two end sills of built up section, two steel platform castings, and an arrangement of floor beams for the support of the air conditioning ice box and other reservoirs.

The center sill was set up on the assembling jig and all other components set in place and held by temporary bolts. The whole assembly was lined up. The bolsters were welded to the center sill by a series of vertical and overhead fillet welds. The platform castings were riveted and welded to the center sill along the lines of contact. The floor beams were each attached to the center sill by two riveted clips at the sides and then with fillet welds to the top of the sill. After the floor beams were applied rigidly, the side sills were fastened to the floor beams and bolsters by rivets and by a butt joint weld at the top of the side sill to the transverse members. Finally the end sills were applied, being fastened also by rivets and a butt joint weld.

The side sills have the same camber as the center sill, in fact the floor

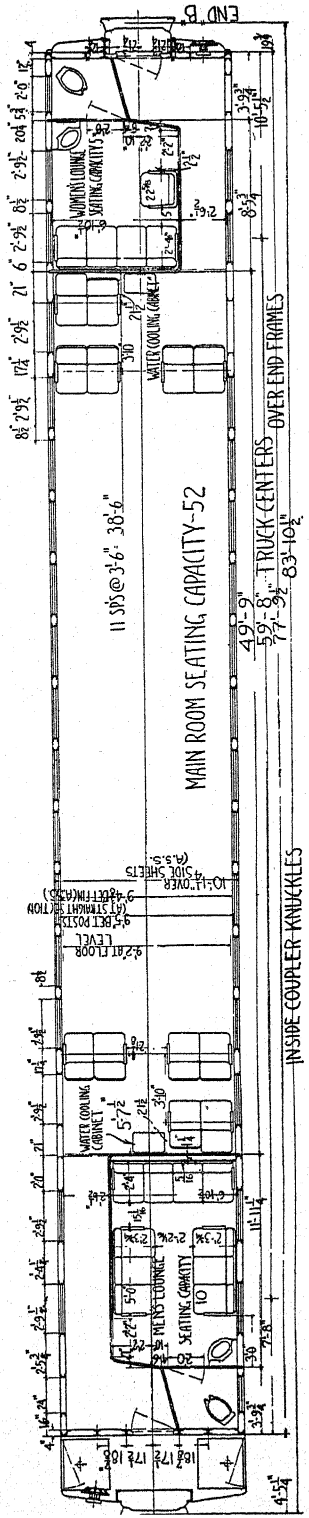


Fig. 1. Floor plan of light weight passenger coach.

beams, bolster and side sills actually support the weight of the center sill which carries no weight vertically but merely absorbs the horizontally applied stresses. This is a departure from the old practice, where the center sill carried not only its own weight but also about 1/3 of the car weight. The new construction permits a decided reduction in dead load. In addition to the above welding, all tank supports and pipe clips were welded to the underframe.

A total of 45 pounds of electrode was used for the above welding including 22 pounds of 1/4-inch electrode and 23 pounds of 3/16-inch electrode. Welding time was approximately 9 hours.

Super Structure and Sheathing.—The superstructure was built up of standard channels, I-beams, angles and special pressed steel shapes, the latter manufactured by the company.

The purlines are made up of 2 channels back to back to form an I-beam, the original intention being to fabricate the sides and roof in jigs and assemble them. However, the sides were not rigid enough to lift without buckling. The rigidity appears after the purlines and side sills are riveted. This is due to the side and roof construction, the side posts and carlines actually taking on the qualities of an inner hoop on a tube. The end construction was practically all riveted and was built up of shapes and pressings.

The side posts, (See Fig. 3), and carlines were pressed-shaped channels made from 1/8-inch sheet to the shapes. The carlines were punched for the rivets to apply the roof. The posts were punched for plug welding through the posts to side sheets. A lot of trouble was encountered here. At first the tacks were not strong enough due to the holes in the posts being too small. The electrode would arc across the hole preventing penetration to the side sheets. These holes were round and 5/16 inches in diameter. They were changed to elliptical holes 3/8x5/8 inches. This overcame the tacking difficulty. However, due to careless welding and the application of too much metal per hole, buckling began to occur in the sheets. Instructions were given to the operators, to keep the metal to a minimum necessary for a good bond and to stagger their welds to keep heat and hence expansion to a minimum. This practically rectified the trouble. At the same time, a paste of asbestos and water was applied along the line of welding to act as a cooling medium and assist in keeping heat to a minimum. Due to the shape of the car, any other form of cooling would have been impractical.

The changes mentioned in the preceding paragraph also were applied to the letter plate stiffeners, (See Fig. 4), window header angles and vertical butt joint channel stiffeners. The channel stiffener was of 3/16-inch material and care had to be shown in punching so that all holes were on the flat part of the channel. Any holes punched partially on the radius caused the sheet to draw in to conform to the radius. These angle stiffeners were applied to the car at the same time as the sheathing.

After plug welding was completed on the car, all the stiffener pieces were welded to their adjacent posts. This welding had been done after the sheathing had been welded but this sequence of welding was changed, as mentioned above. A more satisfactory job resulted since lining up

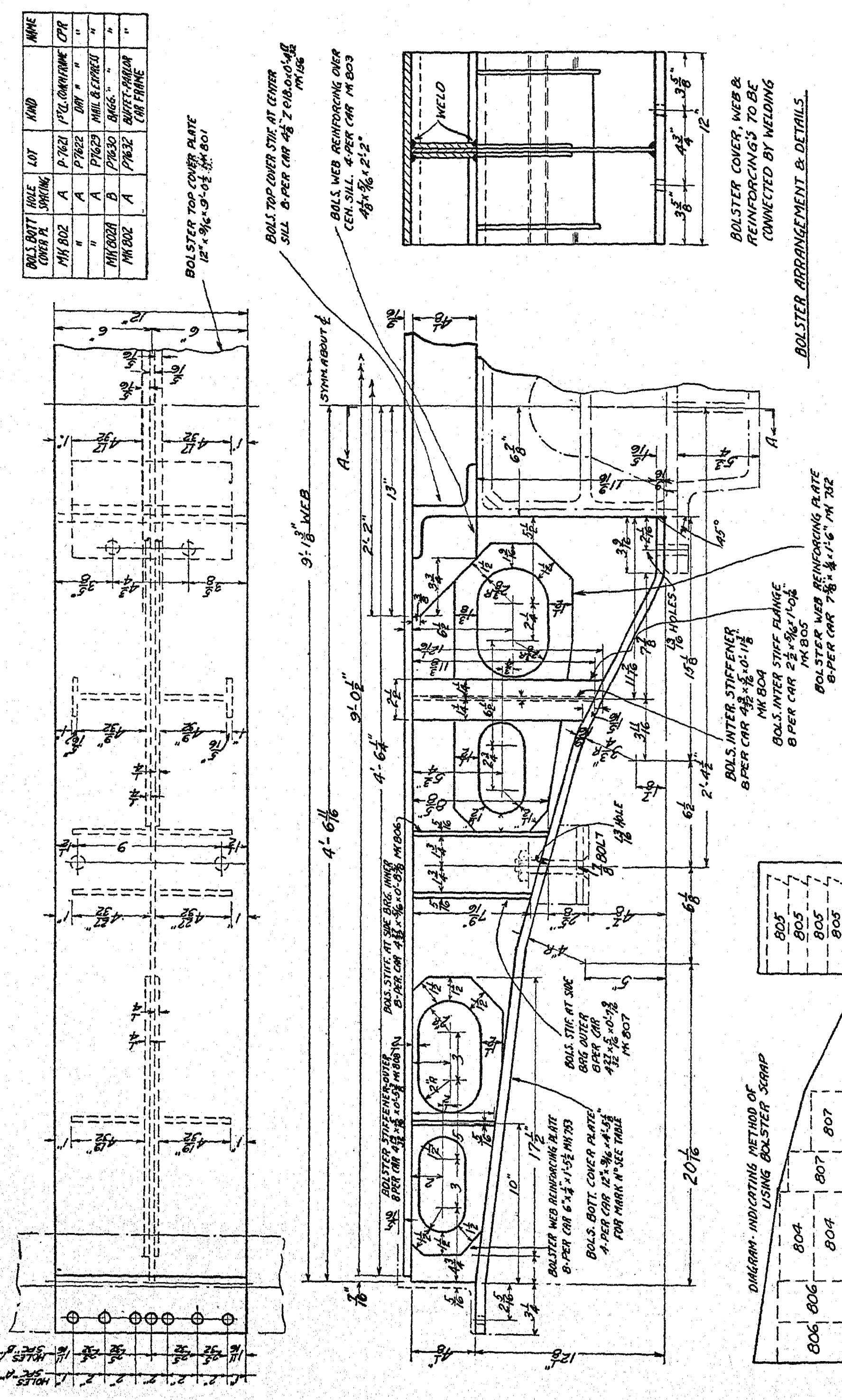
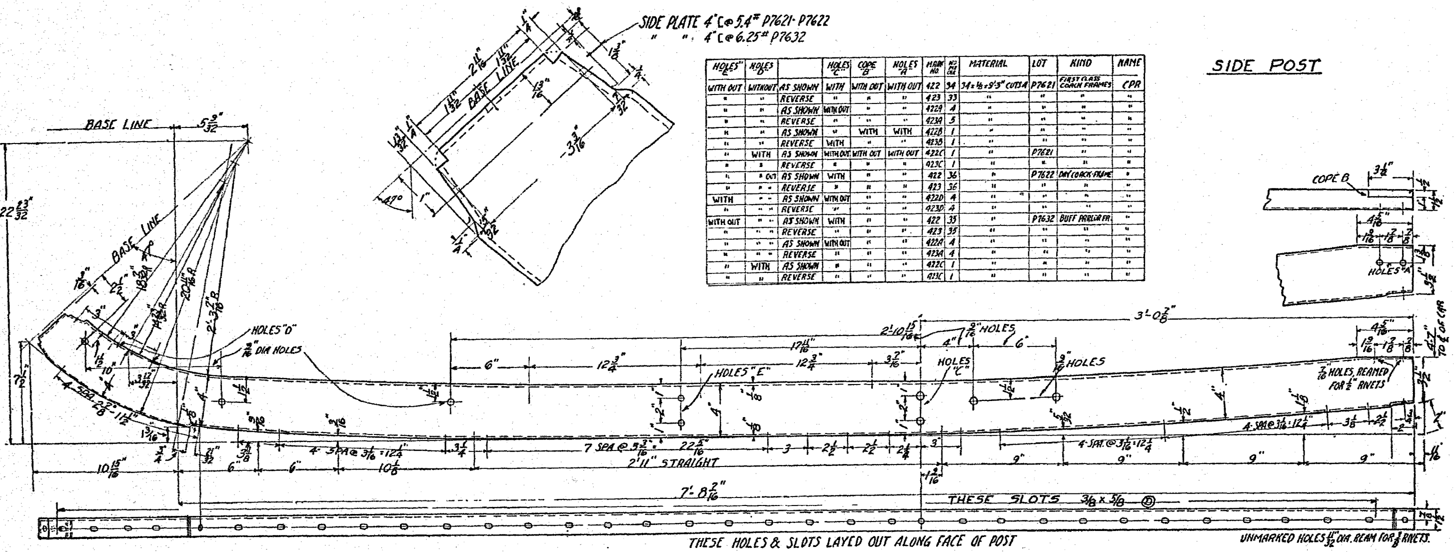


Fig. 2. Details of bolster.



HOLES "E"	HOLES "D"		HOLES "C"	COPE "B"	HOLES "A"	MARK NO.	NO. PER CAR	MATERIAL	LOT	KIND	NAME
WITH OUT	WITHOUT	AS SHOWN	WITH	WITH OUT	WITH OUT	422	34	3/4 x 1/8 x 9'3" CUT 5 A	P7621	FIRST CLASS COACH FRAMES	CPR
"	"	REVERSE	"	"	"	423	33	"	"	"	"
"	"	AS SHOWN	WITH OUT	"	"	422A	4	"	"	"	"
"	"	REVERSE	"	"	"	423A	5	"	"	"	"
"	"	AS SHOWN	"	WITH	WITH	422B	1	"	"	"	"
"	"	REVERSE	WITH	"	"	423B	1	"	"	"	"
"	WITH	AS SHOWN	WITH OUT	WITH OUT	WITH OUT	422C	1	"	P7621	"	"
"	"	REVERSE	"	"	"	423C	1	"	"	"	"
"	" OUT	AS SHOWN	WITH	"	"	422	36	"	P7622	DAY COACH FRAME	"
"	" "	REVERSE	"	"	"	423	36	"	"	"	"
WITH	" "	AS SHOWN	WITH OUT	"	"	422D	4	"	"	"	"
"	" "	REVERSE	"	"	"	423D	4	"	"	"	"
WITH OUT	" "	AS SHOWN	WITH	"	"	422	35	"	P7632	BUFF PARLOR FR.	"
"	" "	REVERSE	"	"	"	423	35	"	"	"	"
"	" "	AS SHOWN	WITH OUT	"	"	422A	4	"	"	"	"
"	" "	REVERSE	"	"	"	423A	4	"	"	"	"
"	WITH	AS SHOWN	"	"	"	422C	1	"	"	"	"
"	"	REVERSE	"	"	"	423C	1	"	"	"	"

Fig. 3. Details of side post.

was easier with partial rather than the completed structure. The superstructure then was rigid in all directions, the side posts and carlines acting circumferentially and the angle stiffeners and purlines acting longitudinally.

After all the tacking had been completed, the sheathing welding was put into progress. The side sheets and side roof sheets were made as long as possible to minimize the number of welded joints. A total of 24 vertical butt welds and 21 horizontal welds were required. These joints were backed by a special 3/16-inch thick-channel backing stiffeners mentioned previously. The drawing called for 1/8-inch gap at the butt joints. However, due to the camber in the car, it was practically impossible to achieve this, and joint widths varied from zero to 1/4-inch. The zero

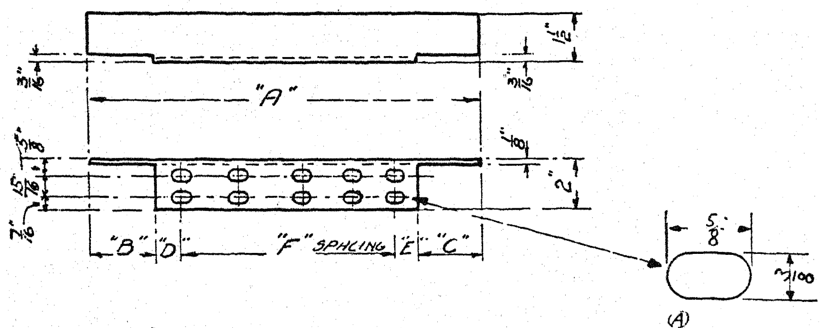


Fig. 4. Pier and letter plate stiffener.

gaps were chipped out to the required dimensions but a special method was evolved for welding the wide gap joints. A single pass was most desirable to prevent too large a heat range. By bridging the gaps every 1/4-inch and then welding across the bridges, the operators, after a little practice, succeeded in doing a very fine job. They advanced their welding beads by the skip method, four inches being the maximum single length of a bead, this method being followed in all the linear welding on the sheathing and was found to keep distortion to a minimum. Carelessness in de-slagging the ends of the beads before recommencing a weld caused some trouble, since on grinding the weld flush with sheets these slag pockets showed up in the form of pores which had to be chipped out and rewelded. In addition, all joints were wedged out 1/8-inch before welding. This was done because we had found that the seams had a tendency to draw from 1/16 to 5/32 inches after welding. This made the maximum draw 1/64 to 1/32 inches. The tolerance allowed for this buckling was 1/8-inch in four feet.

The most troublesome sections on the sheathing occurred at the vestibule end of the car, (See Fig. 5), and consisted of two horizontal welds, each 9 feet long, and one vertical weld from side sill to side roof purline. The horizontal welds were done by the skip method and finally the operators, acquiring the technique, kept buckling to a minimum. The vertical joint was backed against the leg of a light "Zee" bar and the heat of welding caused this leg to buckle outwards. The vertical strips at this point had a rolled edge to finish off the side of the car

and all these strips had been fabricated. In any further orders, this strip will be made wider so that the line of welding will be against a more rigid backing such as a side post.

The side roof sheets were also welded with curved posts carlines, and backing strips conforming to the proper radii. Little difficulty was encountered in this phase of welding since the curved construction acted to resist the bending and warping stresses set up by welding. However, the operators were instructed to proceed as carefully as before and to employ the same technique, experience showing that if they were allowed to become lax in one section of the work, they carried this laxity to other sections.

This car was designed so as to accommodate the maximum number of passengers with comfort. The reasoning followed was, that no more than one vestibule is opened for entrance or exit at anyone time. Thus, there was no reason for a vestibule at both ends. Hence, by making the car with a single vestibule and a blind end, four more passengers can be seated.

The blind end of the car was built up of light channels and "Zee" bars and special shapes to form a header to which the end sheets could be attached. These three sheets were riveted to the header and welded to the side and roof sheets. This welding had to be ground off so that the corners were absolutely square. If the fit-up had been perfect, this weld could have been applied in one pass but due to slight errors in shearing, (which was difficult due to the cross sectional shape of the car), two and three runs were applied. This caused some buckling but this was reduced practically to zero by welding a good sized bead on the inside joints of these sheets and thus compensating the stresses set up by the first welds.

The vestibule end sheets were riveted to an end header and welded to the roof sheets only. The outer weld was similar to that on the blind end, but the inner weld was difficult to apply due to lack of room for proper manipulation of the arc. This lack of room was due to the compartments over the vestibule being arranged to carry the conditioning equipment.

The next operation after the ends were welded, was the roof welding.

The roof design called for the joints to be welded to be prepared as plain butt joints with no backing stiffener at the vestibule end for four feet. The roof is of riveted and welded construction. Twelve feet at the blind end and sixteen feet at the vestibule end consisted of $\frac{1}{8}$-inch sheet with welded joints. The remainder of the roof is $\frac{1}{16}$-inch sheets riveted together. The roof design called for no stiffeners or backing strips on the welded joints. The method of preparing the joints was to flange one sheet about one-inch, and leave the other straight. The exception was the section of the roof over the vestibule where, due to lack of space, the flange was omitted to accommodate the air-conditioning equipment.

This flanging was not very satisfactory, the flange radius and slight variations in shearing making fit-up difficult. Also the stiffener on the one sheet did not assist in stiffening the adjoining sheet sufficiently. The welding was done by tacking at short intervals and then skip welding.

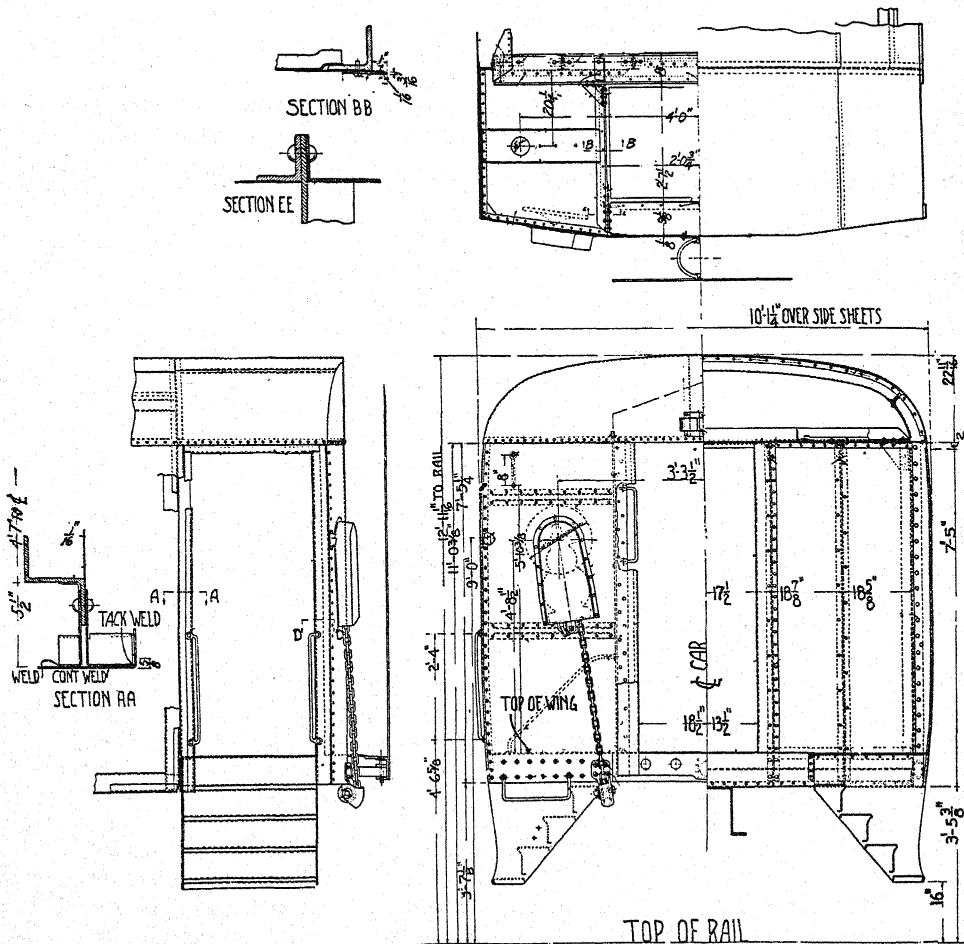


Fig. 5. Details of vestibule end of car. See also page 273b.

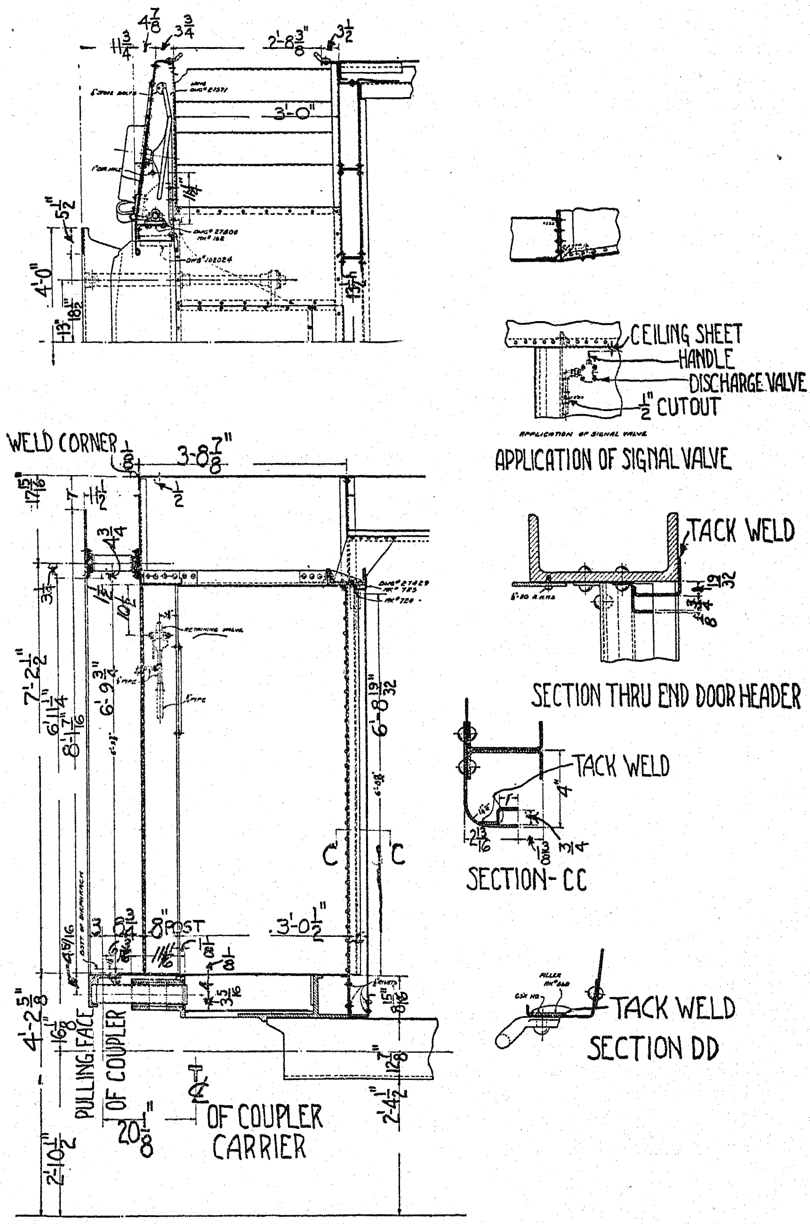


Fig. 5. Details at vestibule end of car. See also page 273a.

Buckling occurred, however, and for future design a "Tee" section stiffener is being considered.

The roof over the vestibule had no support, whatever, not even carlines. This was remedied by making temporary wooden carlines and temporary backing strips. The backing strips were put in position and the carlines were then wedged into place. The results were surprisingly good and that section of the roof caused the least trouble.

As soon as the car was welded, it was moved into the last position prior to sand blasting. The welds on the outside of the car were ground and polished and any weld failures were chipped out and re-welded. Any severe buckles which may have occurred were hammered out. At the same time, the inside stiffeners and insulation strips were being welded into place. These consisted of special channel pressings welded to the side posts and carlines at the lower window line, upper window line and along the side roof lines.

The diaphragm face plates were welded into position and any miscellaneous welding required was then completed. The car was then sent to the sand blast.

After sandblasting, the car was given a priming coat of paint and brought to the OK position. Here, the remainder of the buckles were hammered out and floor sheets were applied. These floor sheets were of 20-gauge galvanized sheets and were welded onto the floor beams. $\frac{1}{8}$-inch coated electrodes were used for this application.

The trucks and air brakes were then applied to the frame which was then ready to be shipped. All the interior finish and final finishing coats were applied at the Angus shops of the Canadian Pacific Railways in Montreal.

The final analysis of the car showed the following rod consumption:

66 pounds of $\frac{1}{4}$-inch electrode (coated)
23 pounds of $\frac{3}{16}$-inch electrode (coated)
10 pounds of $\frac{5}{32}$-inch electrode (coated)
116 pounds of $\frac{1}{8}$-inch electrode (coated)
47 pounds of $\frac{1}{8}$-inch electrode (bare)

The cost of welding could be cut and a better job done if the sheets were spot welded to the superstructure instead of tack welded. The posts would also be stronger as it would not be necessary to punch them. Where four welders and four helpers are employed, one welder and one or two helpers would be able to do a better job in $\frac{1}{4}$ of the man-hours now required. There would be a reduction in electrode weight of about 75 pounds. It might be possible to spot weld the floor sheets to the floor beams in at least half the time, cutting welding and electrode cost.

This car when complete, weighed about 110,000 pounds or about 40,000 pounds less than the standard coach. Some of this weight saving was in the trucks which, due to the light-weight of the superstructure, were four-wheel instead of the standard six-wheel type, and in light weight interior finish such as seats, aluminum trimmings, etc.

Further reduction in weight and greater strength could not be accomplished by the use of tensile steels in this particular design since all

structural members and sheets specified were as light as was practical. By radical changes in design, it might be possible to reduce the light weight further such as by sheet corrugation which would allow the use of much lighter gauge sheets.

This thesis has been an effort to indicate roughly our methods of fabrication and any improvements in design that we were able to accomplish.

Chapter IX—Design of an All Welded Locomotive Tender Tank

By W. C. Rockenstire,
Assistant superintendent, American Locomotive Co., Schenectady, N. Y.

The objective of this study was:

(1) To produce a better locomotive tender tank for less money by the proper design for welding.
(2) To weld this tender at a lower cost and to do this by the design, construction and use of a mammoth ball and socket joint capable of supporting a complete tender tank and thereby placing at least 85% of all welded joints in flat position in order that the welding could be done down-hand and thus at the lowest possible cost.

Until the last few years, all steam locomotive tender tanks have been fabricated by means of riveted construction. The locomotive tender, in addition to carrying fuel for the engine must also carry a very large quantity of water to supply the boiler and replenish that lost through exhaust steam from the engine. A modern locomotive tank has a capacity of from 15,000 to 20,000 gallons.

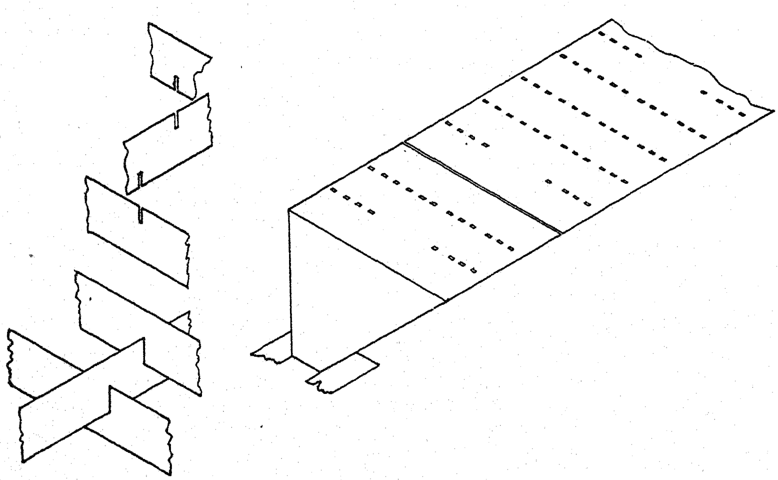


Fig. 1. Baffle construction of locomotive tender tank.

In order to break up and control the surges of water in the tank due to starting and stopping of the train it is necessary to place inside of the tank a system of baffles. This was accomplished by riveting a Tee-section vertically to the sides of the tanks at the location of every baffle. The baffles are then riveted to the web or projecting Tee.

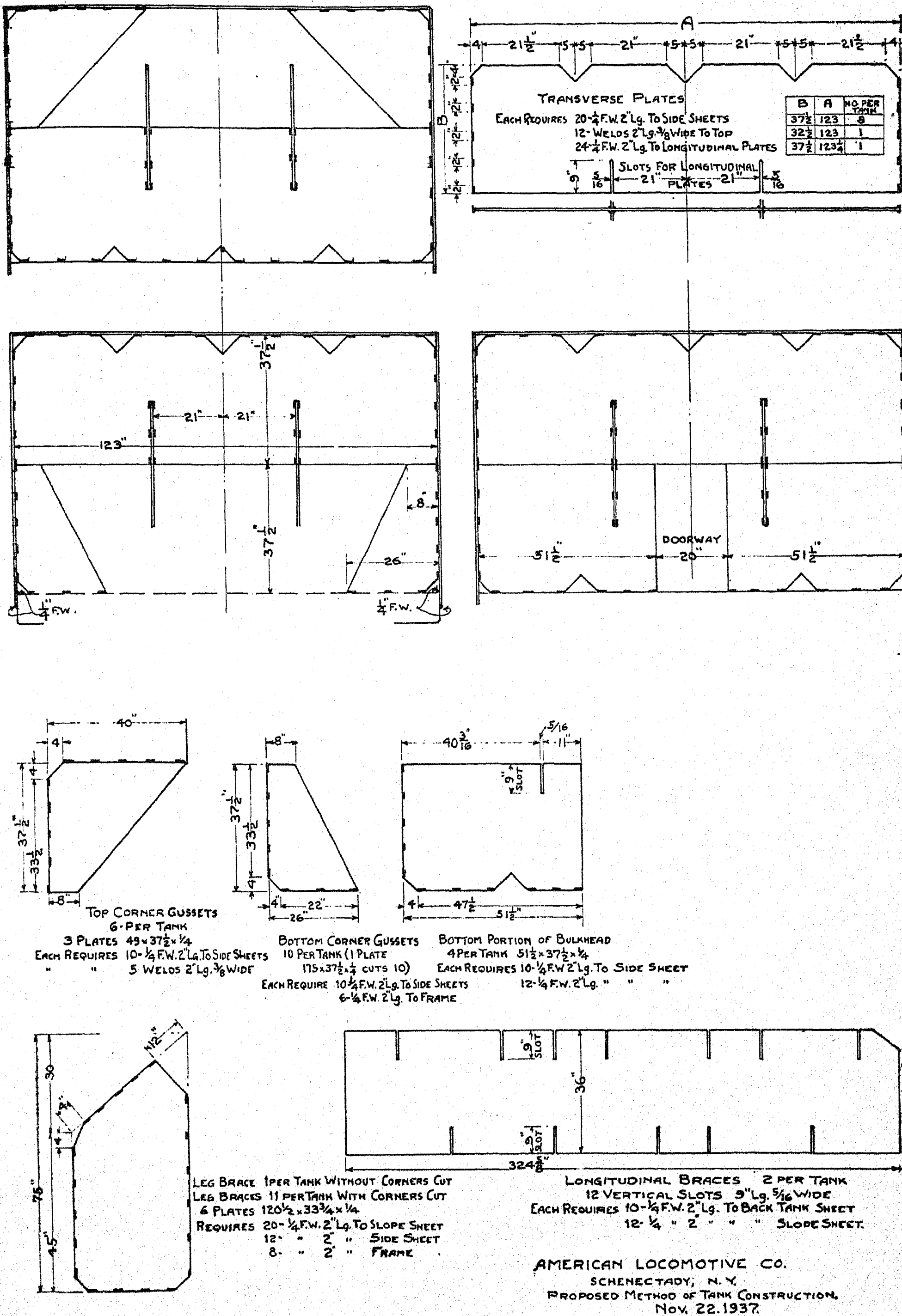


Fig. 2. Details of arc welded tender tank having egg-crate baffle construction.

Note:—It is well to remark here that the use of these Tee irons increases the dead weight of the tender thousands of pounds and it is significant that when we first started welding these tender tanks we preserved this tradition, i.e., the use of Tee irons welded to the sides of the tanks and the baffles welded to the Tee irons. In fact, on an 18,000 gallon tank the actual dead weight of these Tee and angle irons is between 8,000 and 9,000 lbs. This includes the angle iron used at corners of tanks, top, bottom, etc., all of which is eliminated in the new design of tanks which I am submitting for this paper.

Our experience in welding with the new fast shielded arc type of electrode led us to believe that we could replace the some ten thousand ½″ and ⅝″ rivets in a typical tank by welding without making any other changes and still effect a saving. We found that most of this welding, being in the vertical position, speeds were limited and it was necessary to make two and three passes on each weld using 5/32″ coated electrodes. There were approximately 3,000 lineal feet of welding and the average speed obtained was approximately seven feet per hour. In this way we were not able to show a great saving in cost over the riveted construction. Some experimental work done at this time on positioning of the whole tender in order to bring all welding into the down-hand position convinced me that in designing my new tank for all-welded construction it would be necessary to provide for some method of turning the completed tank into position in order to eliminate these long vertical and overhead seams.

Another disadvantage of simply taking a riveted tank and substituting welding for riveting was that in order to fit up and hold the tank in shape and place the baffles in the proper place it was necessary to lay out and punch as many as 1,200 holes and this made great inroads on the saving that we intended to make by welding over riveting. In addition to this, the bolts had to be removed after the main seams were welded and these holes filled up by welding and then ground smooth.

However, the experimental work which we did in supplanting rivets by welding on these tanks which were designed for riveted construction showed us the great possibilities for increased production on a tender tank really designed from the outset for welding. This will now be described.

The Design of an All-Welded Locomotive Tender Tank.—Consider the construction of an ordinary egg box or egg crate, particularly the separators which notch into each other. This constitutes the basis of my all-welded tender tank baffle system.

Fig. 1 illustrates the method of baffle construction and also indicates the method by which the top will be welded on last and which will be discussed at length later on.

Fig. 2 gives a more detailed description of the actual design of the tank.

Note the tremendous simplification of design and layout, the great reduction in dead weight due to the elimination of fitting up parts which were required with riveted fabrication.

Fig. 3 is an isometric sketch of the complete baffle system of my

new tender and I think this illustrates the great advantage of arc welding for such construction, i.e., the elimination of all Tee irons, angle irons, etc., which are necessary to make 90° joints when rivets are used.

Method of Assembly on New Tender.—The actual *modus operandi* of fabrication of this new tender tank will be as follows:

Plates will be brought into the shear and located against a fixed stop, then sheared. This will mean absolute accuracy on all plates, without layout expense. The baffles will then go to the nibbling machine where, by means of locating guides, slots will be nibbled into these plates, again without the necessity of layout. This will produce the interlocking egg crate construction. After being thus sheared and notched, all plates will go to the erecting floor where they will be assembled by means of a jig. With this jig, it will only be necessary to clamp the various members in place, tack weld, remove jig and complete welding.

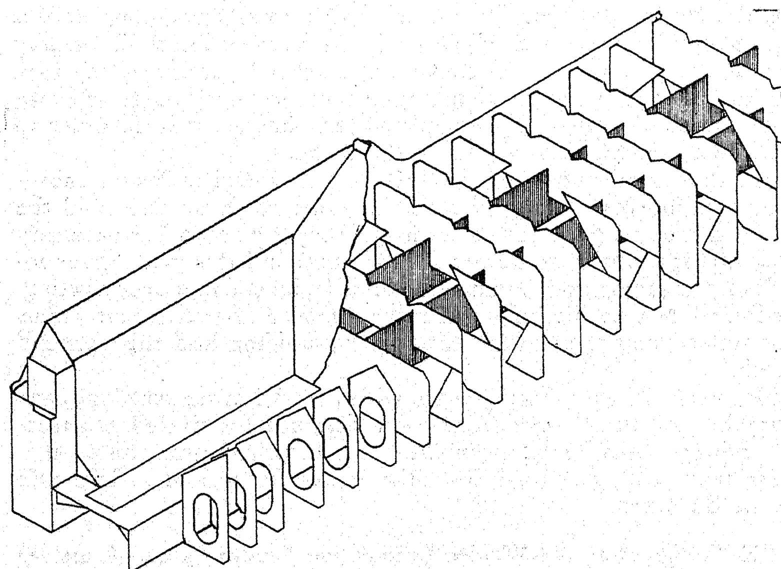


Fig. 3. Isometric sketch of complete baffle system of arc welded tender tank.

However, before the final welding operation is begun and after the jig is removed the second part of my development comes into the picture. This consists of a huge ball and socket joint which will support the complete tender tank permitting turning it in any position necessary to bring the welds into the down-hand position and is pictured in Fig. 4. This permits the use of $5/16''$ diameter coated electrodes in the 18″ length and means a cost saving of approximately 50% for 3,000 feet of welding. There is also a saving effected in cost of electrode due to greater deposition efficiency on down-hand

welding and the lower cost per pound of electrodes in larger diameters plus a further saving of about 8% due to the ability to use greater lengths of electrodes with less frequent stopping of the arc for changing electrodes, etc. In fact, actual tests which we have conducted show that there is an even 50% saving in the cost of rods alone for producing fillet welds with a given throat when using this particular electrode, in 5/16″ size in downhand position, as compared with using 5/32″ electrode and making these fillet welds in the vertical position.

An incidental saving not reflected in the above figures is the possibility of using lower rate welders when welding in the down-hand position. For the vertical welding, it is necessary to hire first class welders, whereas, our extensive tests have shown that a "green" man with the ball fixture doing flat welding only, is able in 100 hours to go on production, turning out very acceptable work.

You will note that in the assembly and fabrication of the tanks so far, the top has been left off completely. This means that men are never working in a confined space with the dangers attendant thereto. In case of any accident or trouble the men can immediately escape from the compartments in which they are welding. They are not so subjected to the fumes and smoke from the welding operation and if

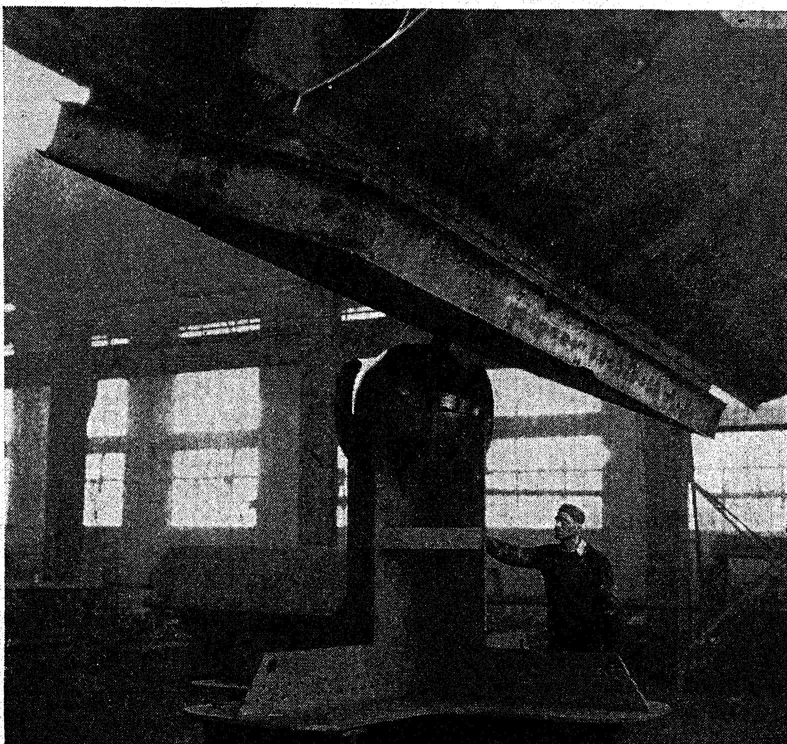
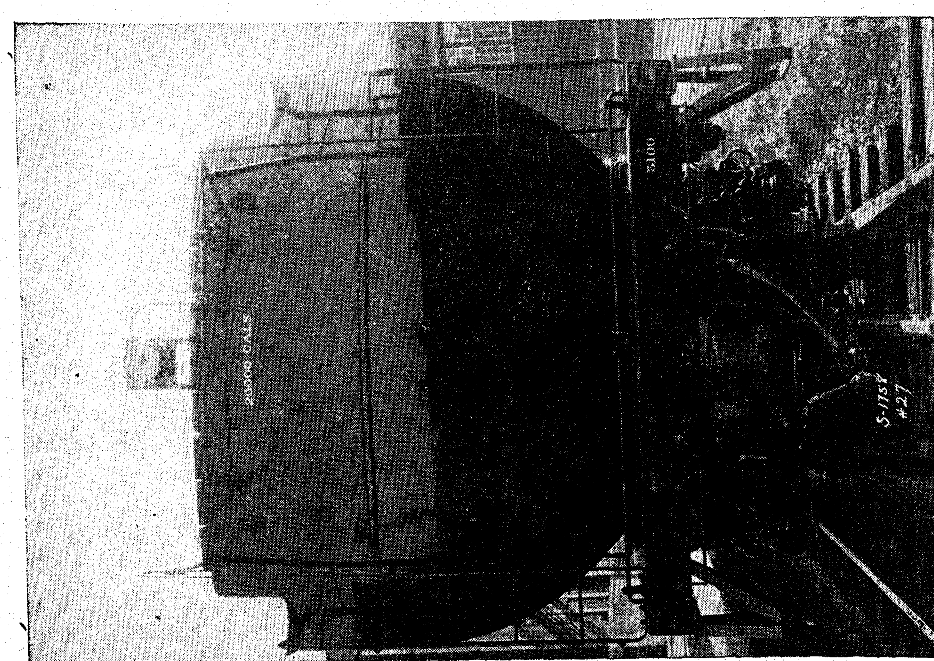


Fig. 4. Ball and socket jig for positioning tender tank to permit all welding in down hand position.



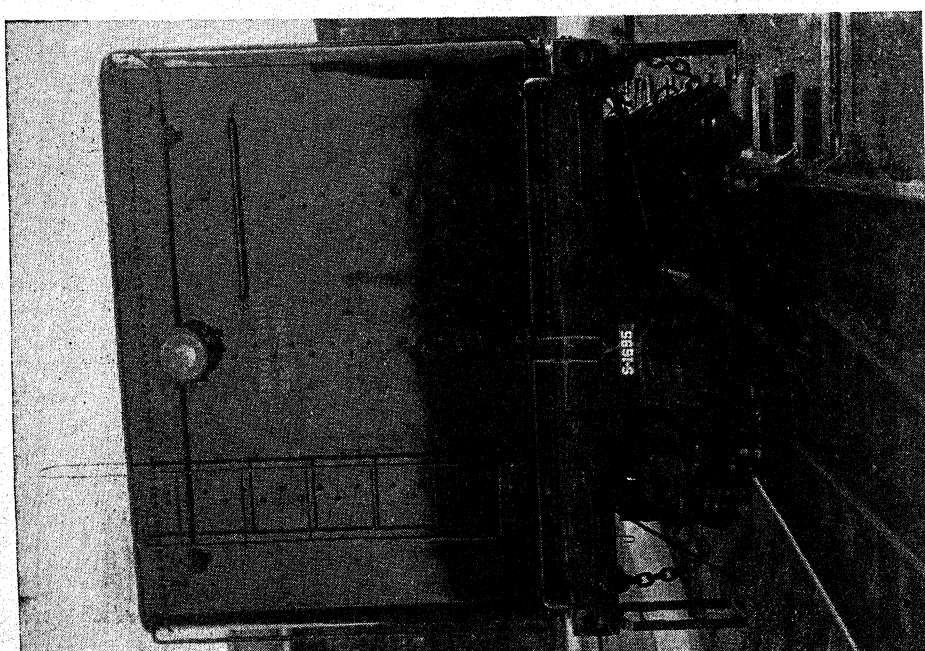


Fig. 5. The old and the new locomotive tender tank. Compare appearance of riveted tank (left) with arc welded tank (right).

for any reason their clothing should catch fire or any other accident occur from unseen causes, the workman can immediately escape.

In this construction the final welding, that of placing the top on the tank, will be done from the outside by means of accurately located slots through which plug welding will be done onto the edges of the vertical plates. The question has been raised as to whether or not this method is practical. The experiments so far conducted indicate that it is completely practical, and due to the fact that all pieces are cut to exact lengths, fitted up and welded with jigs and fixtures, these slots will become accurately located and permit the welders to close in the tanks from the outside. It is my belief that this is a very important detail in the design of this new all-welded tender tank.

Summary.—A completely welded tank is practicable at reduced cost by incorporating properly positioned all-welded joints and baffles, by positioning the tank on the ball and socket fixture so that it may be welded with heavy current and large electrodes, which permit highest possible welding speed and better welds.

The importance of these facts to the railroads can hardly be overestimated. Tender tanks rust out and deteriorate. In the past it has been the practice to repair these from time to time but the operation is expensive and never entirely satisfactory. With the method of construction suggested here, complete tender tanks should be considered when extensive repairs or changes must be made on tanks now in service.

This improvement is predicated on arc welding as that art has been developed to date and has been made possible by the outstanding advancement of equipment, material and technique of research specialists who are continually bettering the practice. It is my belief that purchasers of equipment prefer new, less costly and better designs and I, therefore, offer this as a revolutionary step forward in locomotive tender construction.

Chapter X—Fabricated Parts for Locomotives and Cars

By H. C. VENTER,
Superintendent, Sacramento General Shops, Southern Pacific Railroad Co., Sacramento, Calif.

The adverse economic situation in which most railroads find themselves has stimulated research along various lines and no part of either a locomotive or car is too small or unimportant but that it must stand a close inspection in regard to its first cost and the service it is rendering. This research and investigation has demonstrated that there are certain parts of locomotives and cars that can be fabricated cheaper and give as good or better service than the castings or forgings which they displace.

This paper is divided into three parts, the first part giving the reasons for experimentally fabricating a certain number of locomotive guide yokes to take the place of both forged and cast steel yokes; the second part describing the fabrication of a bolster end to take the place of a malleable bolster end casting, used on freight car bolsters; and the last part dealing with the electric welding of a new and heavier section of locomotive frame to an old and lighter section.

Fabrication of Locomotive Guide Yokes By Electric Welding.—The Southern Pacific Company has experienced considerable difficulty with locomotive guide yokes breaking on engines of the mountain class. Originally, all of these engines came equipped with cast steel guide yokes, all of which eventually failed in service and had to be welded and reinforced. These guide yokes support part of the weight of the piston and side rod and it is safe to assume that the weight of the two above mentioned reciprocating parts have no bearing on the breaking of the guide yoke. The real cause of failure is the forward and backward thrust of the crosshead, which causes an alternating stress in the guide yoke with each revolution of the driver.

An examination of the fractures of some of these guide yokes reveal blow holes, which reduce the effective cross sectional area of the supporting arm and induce strain concentration, which ultimately results in a fracture. Undoubtedly when blow holes are present they are the principle contributing cause of failure, but in instances where blow holes are not present, it is difficult to determine the cause of failure.

As a result of the poor service given by cast steel guide yokes and the uncertainty existing as to the presence of blow holes, this company decided to substitute forged steel in place of cast steel. Although the forged guide yokes cost more than the cast steel, the former give the better service.

About this time the question was brought up as to how a fabricated guide yoke would compare in cost and in service with both the forged and cast steel yokes. Therefore, a yoke was fabricated by electric welding from 1¼″ thick boiler plate, as shown in Fig. 1. The main supporting arm marked "I" has to hold the insert through which the

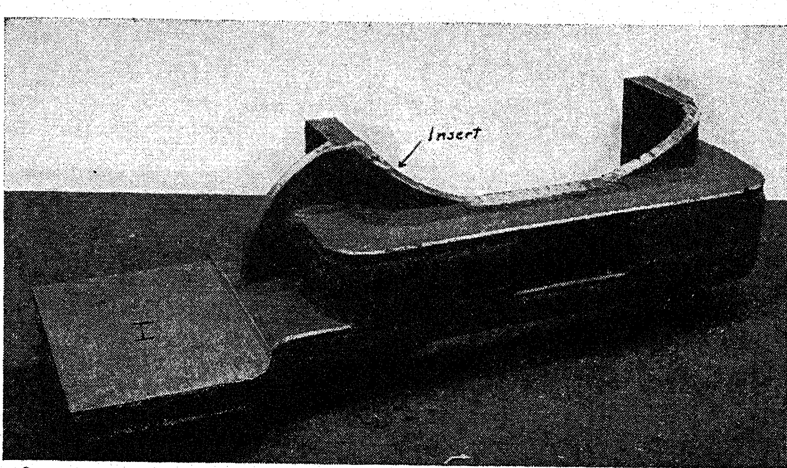


Fig. 1. Locomotive guide yoke fabricated by arc welding of 1¼-inch boiler plate.

cross head reciprocates. It was made of two thicknesses of 1¼" boiler plate steel, electrically welded together, while the rest of the assembly was made of single 1¼" thick boiler plate. Only one guide yoke was made from boiler plate steel, on account of its low tensile strength, which was thought to be too low for this particular purpose. This one yoke has been in service for several months and so far has given satisfactory service.

The next guide yokes were made from bloom steel of a higher carbon content and considerably higher tensile strength. This material was hammered out into plates 2½" thick and cut to shape while hot with an acetylene torch. The main supporting arm in this case was a single hammered plate 2½" thick, as shown in Fig. 2. The guide yoke was then built up from cut shapes similar to the one made from boiler steel. All welding was electric and all welds were "V" notched on both sides of cut shapes.

First, the main pieces were tack welded to the main or supporting arm, marked "I" in Fig. 2. They were then checked for alignment and size before welding rigidly in place.

The last operation was to weld in the reinforcing plates between the two main plates and to weld in the strengthening triangles. The comparative costs of the fabricated locomotive guide yoke, as compared with both the cast steel and forged yokes, are as follows:—

Steel Casting

1. Cost of casting	$59.00
2. 8% Store expense (8% of cost of material)	4.72
3. Machining	20.62
4. 15% Shop Expense (15% of all shop labor)	3.10
Total Cost	**$87.44**

Steel Forging

1. Cost of material:	
(a) Bloom steel, 1200 lbs. @ \$2.64 cwt	\$31.68
(b) Welding rods, 60 lbs. @ 10¢ lb	6.00
(c) 8% Store Expense	2.91
2. Cost of Labor:	
(a) Forging	25.76
(b) Welding Guide block to yoke	14.56
(c) Machining	20.64
(d) 15% Shop Expense	10.70
Total Cost	\$112.25

Fabricated from Boiler Steel

Cost of Materials:	
1. Boiler steel 1¼″ thick, 1000 lbs. @ \$3.12 cwt	\$31.20
2. Welding rods, 130 lbs. @ 10¢ lb	13.00
3. 8% store expense	3.54
Cost of Labor:	
4. To set up and cut	4.00
5. To weld	20.00
6. Machining	16.00
7. 15% shop expense	6.00
Total Cost	\$93.74

Fabricated from Bloom Steel

Cost of Materials:	
1. Bloom steel, 1000 lbs. @ \$2.64 cwt	\$26.40
2. Welding rods, 100 lbs. @ 10¢ lb	10.00
3. 8% store expense	2.91
Cost of Labor:	
4. Forging billet down to plate	16.82
5. To set up and cut	3.24
6. To weld	17.20
7. Machining	16.00
8. 15% shop expense	8.00
Total Cost	\$100.57

The 8% store expense is to cover overhead in handling materials. The 15% shop expense is to cover overhead in machine shop, such as supervision and inspection, etc.

The comparative costs of the manufactured guide yokes are as follows:—

Cast Steel	\$ 87.44
Forged Steel	\$112.25
Fabricated from 1¼″ Boiler Steel	\$ 93.74
Fabricated from 2½″ Bloom Steel	\$100.57

The reason for the guide yoke made from boiler steel costing almost as much as the yoke made from bloom steel is that more welding and welding rods are required and also that the boiler steel costs more than the bloom steel.

These figures show that a saving of 12% can be made by fabricating as compared to forging guide yokes, and if the former give as good and, it is hoped, better service than the forged, the latter will, in due time, be replaced by fabricated yokes.

In addition to experimentally fabricating a certain number of guide yokes for the mountain class engines, several experimental guide yokes have been fabricated for the AC-1, 2 and 3 class engines. These guide yokes are smaller than the yokes fabricated for the mountain class engines and weigh approximately 700 lbs. against 900 lbs. for the mountain class. They also can be fabricated for approximately 12% less than forgings.

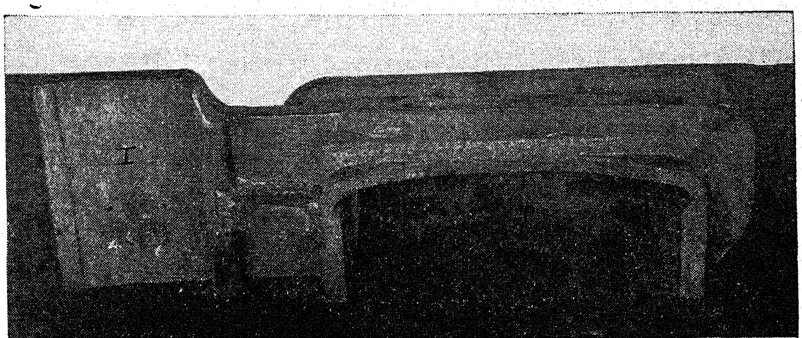


Fig. 2. Locomotive guide yoke fabricated by arc welding of 2½ inch bloom steel.

Fabricated Bolster Ends for Freight Cars.—This part of the paper deals with the fabrication by electric welding of a bolster end for freight cars, which this company has developed to take the place of malleable castings for this purpose. It is not often that a cheaper product will also give better service, but this is what the fabricated bolster end has accomplished. Instead of being purchased as malleable castings, the bolster ends are being fabricated in our own car shop, and it is expected that about 2300 bolster ends per year will be needed for replacements. Eventually all malleable bolster end castings will be replaced by fabricated bolster ends.

As previously mentioned, a considerable saving in first cost and better service is obtained from the fabricated bolster end as compared to the malleable casting. One of the chief advantages of the fabricated product over the malleable casting is that the former can be welded, while the latter does not lend itself readily to welding, and on that account it is usually brazed. When a malleable bolster end wears or breaks, it is either scrapped or repaired by brazing, and since the brazing material is soft, the life of a repaired bolster end is short, which will not be the case with the fabricated product.

The bolster end is really a cap fitting over the end of the bolster, which is placed there to take care of the side wear that occurs on each side of the bolster proper, where it slides up and down in the truck side frame. The wear on the bolster end will vary according to the condition of the road bed, the number of curves and the manner in which the car has been loaded.

The fabricating bolster end, (See Fig. 3), is really an open box with no top or bottom. It has only three sides and instead of a fourth side, a

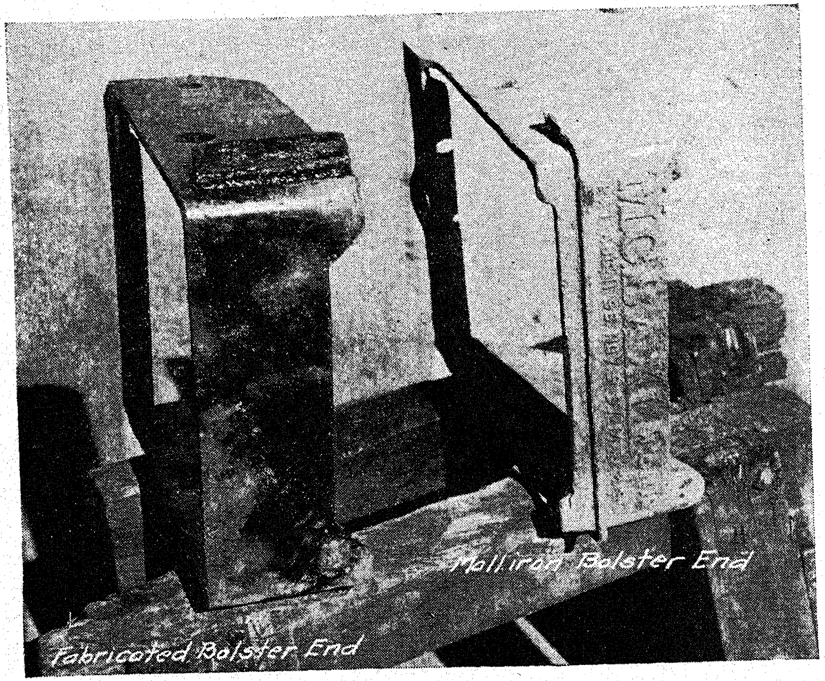


Fig. 3. Arc welded (left) and cast iron bolster end for freight car.

tie-bar is used. It is necessary to have one side partially open with an angular tie bar in order that the tie bar can fit up to the tension member, which is underneath the bolster proper and supports it at an angle, similar to a tension member on a bridge.

In the fabrication of this product, boiler steel 1/4″ thick is used for three sides, while 1/2″ thick boiler steel is used for the tie bar. Two right angle bends are made cold, while the tie bar is formed in a die. There are four welding operations. A lug is welded on each side, and each end of the tie bar is welded to the frame. The tie bar comes out of the die in a wedge shape, since it is required to fit against the tension member supporting the bolster itself.

The fabricated bolster end weighs 27 lbs. and the casting 31 lbs., which makes the fabricated product four pounds lighter than the casting. The manufacturing costs are:—

Material	
Boiler Steel, 27 lbs. @ $2.95 cwt.	$ .80
Welding Rods, 1/4 lb. @ 10¢ lb.	.025
8% Store Expense	.066
Labor	
Tie bar "C" (made in die)	.03
Welding, drilling, shaping	.60
15% Store Expense	.095
Total	$1.616

The fabricated bolster end costs $1.616 to manufacture, while the malleable casting for the same purpose costs $1.77, which represents a saving of $0.154 for each fabricated bolster end as compared to the malleable casting and, in addition, better service is obtained from the former.

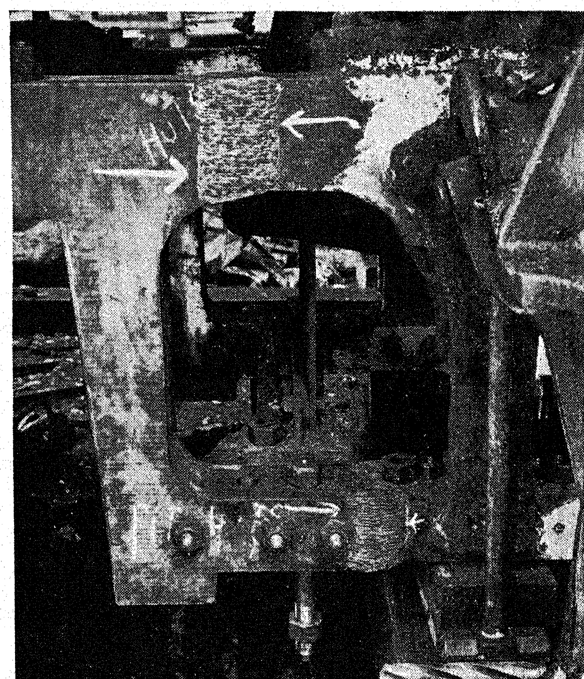


Fig. 4. New section of locomotive frame arc welded to old.

Welding of a New Section of Locomotive Frame to Part of the Old Frame.—It is believed that the following method of welding a new and heavier section of a locomotive frame to part of an old and lighter frame, is somewhat unusual. (See Fig. 4).

A certain class of engine used by the company apparently has a weak frame for it has a tendency to break back of the cylinders. Instead of the usual practice of welding and reinforcing the welds of the old frame, a heavy section of a new frame (heavier than the original) is welded to the old frame. No reinforcing bars or plates are used in these welds and they are built up as a solid weld. Locomotive frames so repaired are giving very satisfactory service and since adopting this practice some three years ago, there has not been a single failure of any frames welded as described in this article.

To successfully weld these frames together requires careful alignment and good welding, all welding being electric, using shielded arc rods. The frame members to be welded are cut back to an angle of approximately 45 degrees to form a V notch on both sids of each member, and all rust and scale adjacent to the part to be welded is removed. The new frame is carefully lined up with the old frame and trammed. It has been found from experience that contraction can be taken care of if the new frame is jacked back 5/32″ from the old. Perfect alignment is maintained by working two welders simultaneously, one on each side of the same frame member. When the weld is about half completed, the jack is removed and the weld finished. After the weld and the metal adjacent to it have been allowed to cool, the frame will have contracted down to the desired length and the whole frame is in perfect alignment. When necessary, these welds are heat treated, which depends upon the location and size of weld. Electric welding for this purpose is faster and costs less than thermit welding, and is more satisfactory.

Chapter XI—All Welded Steel Locomotive Tender Frame

By WILLIAM SIMONS,
Superintendent of shops, Cliffs Dow Chemical Co., Marquette, Mich.

The Cliffs Dow Chemical Company at Marquette, Mich., a subsidiary of the Dow Chemical Company at Midland, Mich., is a large user of arc welding. This organization does all of its own construction and maintenance work. Around a chemical plant where the maintenance department has to contend with corrosive conditions, the arc welder saves about 60% of the cost of maintaining pipe lines, stills, pots and containers. While our fleet of welders is used continuously, there was one job which we had several months ago that proves exceptionally well the savings that can be had through arc welding.

We operate our own railroad which is set up inside of the plant. The rolling stock consists of two 53-ton steam locomotives, one steam crane, about one hundred standard cars (flats and boxes), and 750 retort cars, besides all foreign cars shipped in and out of the plant.

The tenders on the locomotives were of wooden construction, 10″ x 12″ oak beams and 10″ x 10″ cross members. Due to the moisture, the timbers on one of the tenders gave way and the back draw head tore loose. This called for a new tank base in a hurry as we would have to rent a locomotive from the railroad that services us, and the rental of a locomotive runs into money very quickly.

I got in touch with our chief engineer and we went over the cost and time the engine would have to be laid up on both a solid steel riveted job and a welded job; also the strength of each when completed. There really was no comparison between the two. On the riveted job we would have been held up for four days before the work could be started as the engineering department would have to draw up the plans and detail each piece separately for rivet holes, anchors and so forth. Then the steel would have to go through the shops and be laid out, cut and drilled; then delivered to the roundhouse to be set up and riveted. Whereas, with the welded job, actual construction was started at once. The steel was delivered direct to the roundhouse and laid out, cut and welded on the job. The design of the frame is shown in the accompanying illustration.

I used 1 man on the lay out, 2 men and 2 helpers cutting with the acetylene torch and setting up ahead of the welders. One welder started at noon the first day and another welder started the following morning. The cutters first cut and formed the two end beams. The back beam was formed out of a 15″ I-beam with a piece cut out of the web on each end so the flange could be bent up to intersect with the 10″ outside beams. The reason for using such a heavy beam was to give support to the coupler on the back of the tender. With a smaller beam the coupler would have had a tendency to bend down when the engine was shoving a long string of cars. The front beam was formed the

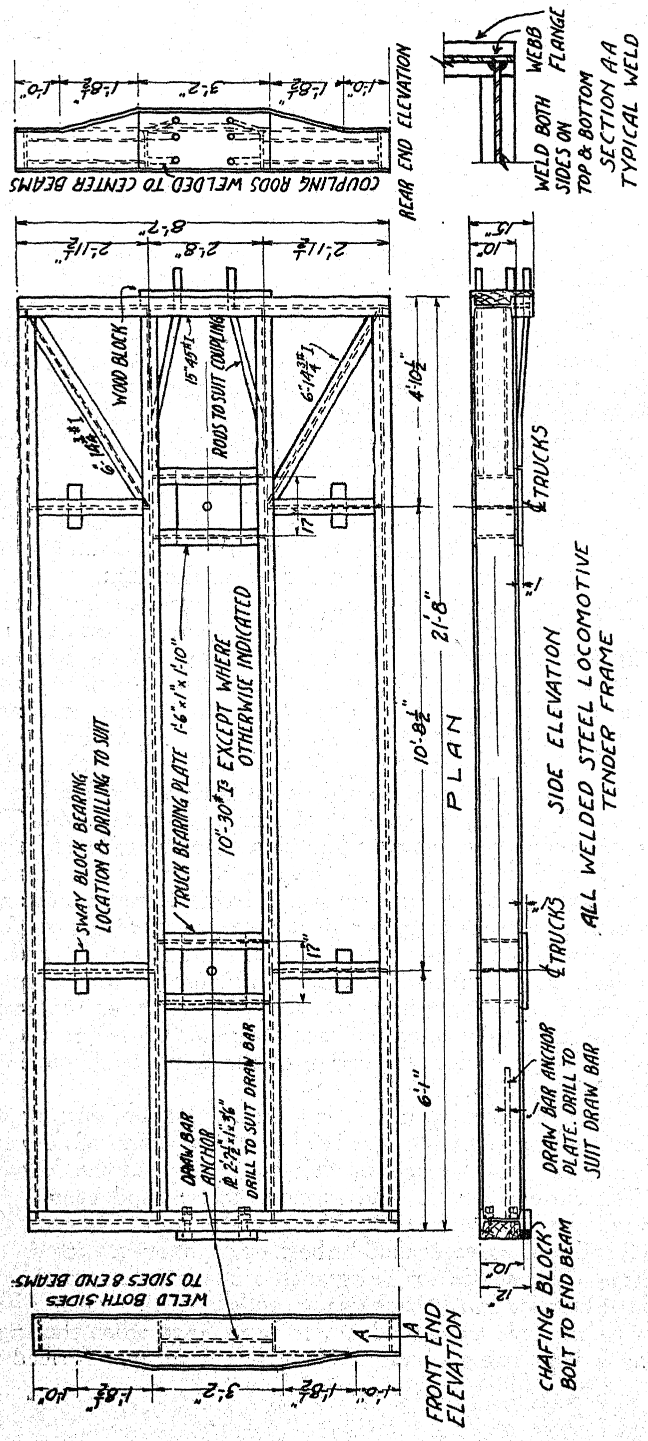


Fig. 1. Design of locomotive tender frame for arc welded construction.

same way except we used a 12″ I in front to support the chafing block between the engine and the tender.

As soon as these two beams were formed the welder went to work welding the flange and web together where the tapered piece had been cut out. Next the cutters cut the side and center beams to length and coped them to fit the two end beams. Timbers were placed across the pit and leveled up, side and end beams were assembled on top of the timbers, squared up and tack welded.

While the welders were welding this frame up solid the cutters cut four short support beams to go over the trucks. These were coped to the two center beams with a 1″ steel plate welded across the bottom to which the truck bearings were secured. The main draw casting between the engine and the tender was bolted to a 1″ steel plate which was welded between the two center beams and to the front beam; two of the bolts to the chafing block were also welded to this plate.

Two knee braces made up of 6″ I-beams were welded in from each rear corner to center beams. These were put in to relieve the strain on the back corner of frame when cars were being pushed with the pole. Then four pieces of 10″ I-beam were welded in, two on each side, spaced over the center line of the trucks. The sway blocks were bolted to the bottom of these 10″ beams.

The draw head casting for the rear coupler was bolted to the back bearing. In order to have a good bearing surface a cushion block made out of oak 18″ x 20″ and 4″ thick was coped to fit between the flanges of the 15″ beam and fit tight against the web. There were six $1\frac{1}{4}$″ draw bolts holding the draw head. Holes to correspond with the holes in the head were drilled in the cushion block and burned through the 15″ I-beam, these bolts being spread after passing through the beam and welded to the sides of the center beams just back of the back truck bearing beams; thus all the strain of a pull was transferred to the two center beams. The chafing block was bolted on to the 12″ beam with $1\frac{1}{2}$″ bolts using a cushion block to give a good bearing, similar to the back block.

After the frame was all welded up, it was jacked up so the trucks off the old tender could be rolled in under the new frame. The frame was then lowered onto the trucks and pinned in place. A wooden deck of 3″ x 12″ fir was bolted on and the tank set on and secured.

The job was started on Saturday morning. We worked Saturday, Sunday, Monday and Tuesday. Wednesday morning the locomotive was back on the job. In this way we got through with only two days' rental on a locomotive as we work only one engine on Saturday afternoons and Sundays. The following is an estimate of the cost of a riveting job and the actual cost of the welded job. This estimate does not include items which would cost the same on a riveted job and a welded job, such as painting steel I-beams, carpenter work and pipe fitting.

Riveted Job

Labor: 340 Hours.	
Material: Engineering Department, (Plans, detail drawings)	$ 70.00
Extra steel needed—	
1000 lbs. angle iron @ $3.50 Cwt.	35.00
400 lbs. rivets @ $3.00 Cwt.	12.00
Bolts, nuts and washers, and 4 long draw rods	11.00
Total	$128.00

Welded Job

Labor: 212 Hours.	
Material: Engineering Department (rough sketch with dimensions)	$ 10.00
Extras—125 lbs. welding rod @ $10.80 Cwt.	13.50
Bolts, nuts and washers	3.20
Total	$ 26.70

Comparison

Labor:	Riveted Job	340 Hours
	Welded Job	212 Hours
	Total saving on Labor	**128 Hours**
Material:	Riveted Job	$128.00
	Welded Job	26.70
	Total saving on extra material	**$101.30**

Plus approximate saving on locomotive rental.. 50.00

Amount saved by using welded construction..$151.30 plus 128 hours

By using welded construction, the weight of this tender was approximately 1000 pounds lighter than a riveted job. The cost of air for riveting and electric rivet heater offset the cost of the welding machine.

This tender has been in service about four and a half months* and is very satisfactory. During the big blizzard on the 25th of January of 1938, we used this locomotive with the snow plow, with our second locomotive coupled to the head end to help push. In places the drifts reached a height of ten to twelve feet and packed solid enough for a man to walk on. Both engines took a terrific beating, hammering their way through the drifts to clear the yard tracks so business could be kept moving.

From my experience with this particular job, it seems to me that the American railroads are overlooking a very good bet to cut not only building costs but also rolling stock tonnage where weight is not necessary.

* At time paper was written.

SECTION IV

WATERCRAFT

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7—C. PERRY STREITHOF
8—MILO BAILEY
9—J. MURRAY WATTS
10—ELLIOTT GARDNER

SECTION IV
WATERCRAFT

Chapter I—Modern Methods and Modern Steels in Welded Ship Construction

By Dr. P. Schoenmaker and Ir. G. de Rooy,
Chief metallurgist, Smit-Transformerworks, Nijmegen, Holland, and Chief, construction department of submarines, Royal Dutch Navy, Voorburg, Holland, respectively. Complete paper contained 27,000 words, 178 illustrations.

One of the fields where the progress of the electric welding process is most clearly demonstrated, is in shipbuilding. Already from the very beginning electric welding was used in shipbuilding and in this sphere has always played an important role.

Electric welding of various parts of the ship gives such enormous savings in weight and also in cost that the advantages obtained more and more induce extensive application of this process.

The authors however did not desire to limit themselves to a description of welded construction only, but have gone a step further and by their investigations have opened an entirely new field in the realms of the electric welding process.

Generally speaking, with welding one was limited to the ordinary construction steels of normal strength, the so called mild steels, having a tensile strength of 55,000-60,000 lbs. per square inch. The modern construction technique demands, however, steels of greater strength, steels with a tensile strength of 75,000-80,000 lbs. per square inch, which permit much greater stresses.

Electric welding of high tensile steels provides savings which are twofold:

a. The well known saving obtained by using electric welding as connecting method, and
b. The saving obtained through the use of steels with higher tensile strength. This economy is caused by the higher stress limit allowable which increases about proportionate to the yield point and represents a weight saving of about 15%.

The authors have gone to a great deal of trouble to solve the above mentioned problems and in the following article they give a review of the investigations with regard to the weldability of the high tensile steels and describe examples of the application of welding of such steels in ship building, particularly in the construction of battleships and submarines where saving of weight and space play an exceedingly important role.

In this way this article gives a complete outline of one of the most modern fields of electric welding technique which, at the same time, contributes to the development of modern ship construction.

When we trace the history of welding applied to ship building, we find, that next to an ever-increasing application in the construction of smaller and larger parts, foundations etc., the building of all-welded

ships, at least as far as deep-sea vessels are concerned, has generally speaking been limited to smaller tankers, coasting vessels and yachts of which the "Fullager", built in 1920 and claimed to be the first all-welded seagoing vessel, is a well known example, has clearly proved the advantages and reliability of electric welding. Notwithstanding that this vessel was thrown on the rocks and had to struggle with very bad weather, the hull remained in excellent condition. Since that time, electric welding has steadily been more and more developed and researches have been made to discover construction methods which are especially suitable for welding.

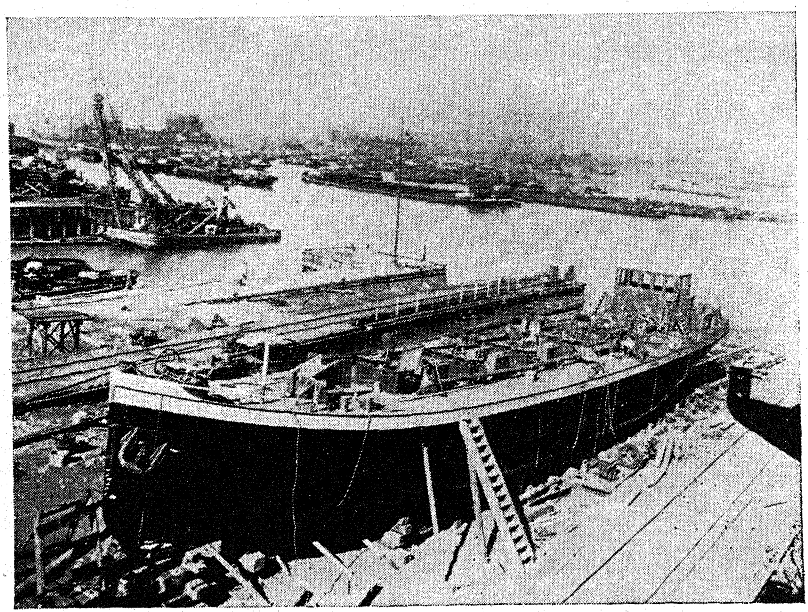


Fig. 1. All-welded 250-ton tanker

In the last few years, a great number of all-welded ships have been constructed for inland navigation, examples of which are given in Figs. 1 and 2. Fig. 1 shows a small tanker having a carrying capacity of 250 tons. Fig. 2 shows a tindredger destined for the tin-works in the Dutch East Indies. As far as larger deep-sea vessels are concerned, welding is limited principally to the interior construction, of which the modern tankers built in England and in America are already living examples of the important improvement made in the welding process and the great confidence that is rightly placed in the quality of the welded joints and the equipment of the ship, while in the construction of the hull very little riveting work is replaced by welding.

The considerable weight saving which is obtained by welding, has been the reason that the application and development of the welding process in naval construction has been much more speedy and extensive than in the mercantile marine.

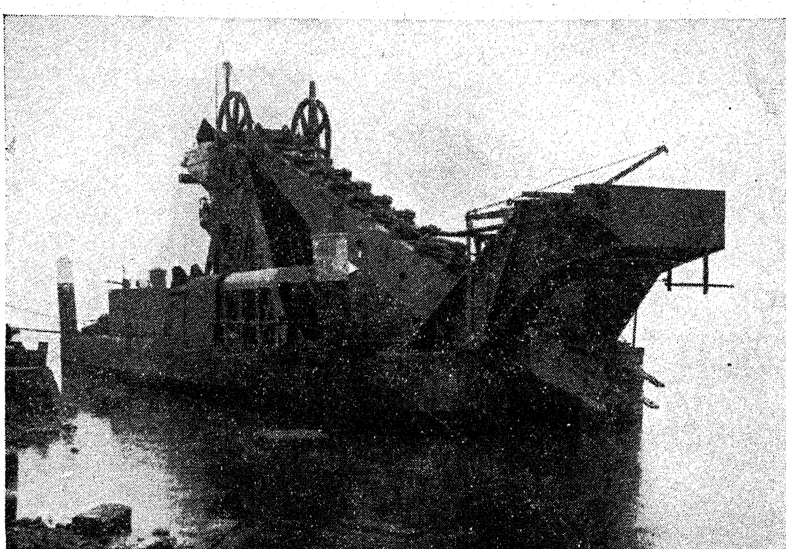


Fig. 2. Arc welded tindredger.

A good example of an all-welded construction is illustrated by a floating target, 65 meters long and 6 meters wide, built in 1933. The hull of this "ship" is composed of a bow and a stern and separate "slices" each 8 meters long and weighing about 12 tons. This construction is chosen, because in this manner, by a direct hit, only a small part of the "ship" fills up with water, so that it becomes possible to keep the target afloat even after several direct hits.

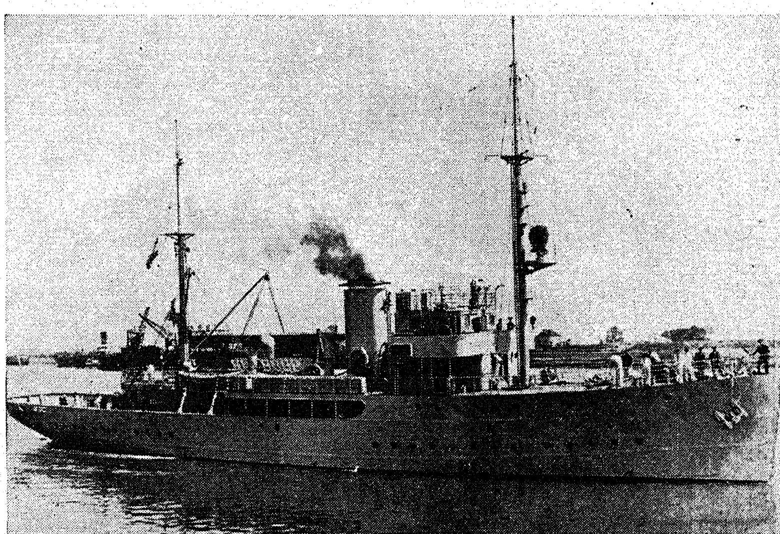


Fig. 3. Police boat of arc welded construction.

In 1932 the flotilla leader "Johan Maurits van Nassau" had its armour plates as well as the joints and the joists entirely electrically welded.

Also the police boat for the fishery protection on the North Sea "Jan van Brakel" (Fig. 3) built in 1935, had important constructional parts of the hull, which because of their strength play an important role, i.e. decks, bulkheads and engine beds, electrically welded.

Of the 1936-built torpedo-work-ship "Mercuur" (Fig. 4) the skin, decks, etc., are entirely electrically welded.

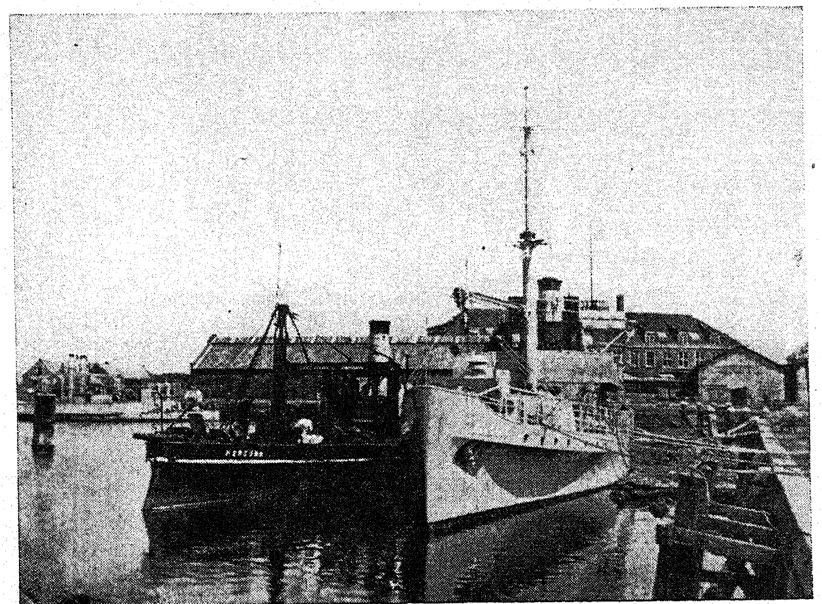


Fig. 4. Arc welded torpedo workship.

A still more extensive application of electric welding was used in the building in 1936 of the cruiser "De Ruyter". The rudder, weighing 12 tons, the inlet for the circulation water (the arched case is at places of the short curves welded with socalled notches and is an example of sheeting, that by a riveted construction would be impossible in this form), the engine bed for thrust block and gearing casing, were arc welded.

Electric Welding of High Tensile Steels.—Electric welding of the usual mild steel no longer offers a single difficulty and the joints, provided they have been made with coated electrodes of good quality, are of such homogeneity and tightness, that perfect security can be guaranteed.

On the other hand, when welding high tensile steels many difficulties were at first encountered and only after profound researches and col-

laboration between consumers and manufacturers were favourable results at last obtained.

To investigate the mechanical characteristics of welds in high tensile steels and the eventual influence of the composition, a very extensive series of tests were taken with two kinds of steel, namely, a chromium-silicon-copper steel and a manganese-silicon-copper steel both welded with a heavy coated electrode of high quality.

Chemical composition of two types of high tensile steel.

Steel	% C	% Mn	% Si	% Cr	% Cu
A	0.19	0.96	0.52	0.35	0.54
B	0.19	1.41	0.30	....	0.34

The investigations were made with the aid of the following tests. 1, tensile test; 2, bend test; 3, impact test; and 4, fatigue test.

These tests were taken with the non-welded plate material and with the welded joints. All specimen bars were taken from a ½″-plate; for the welded joints a V-weld of 90° was made. All bars were smoothly finished on all sides.

1. **The Tensile Test.**—The tensile strength of the plate metal comes to approximately 80,000 lbs./in^2 and the weld to 76,000 lbs./in^2 which therefore meets the requirements. Of great practical importance is the fact that the yield point of the material is practically equal to that of the weld metal.

The characteristics of the weld metal were determined on round test bars which were obtained through depositing in an angle bar so much metal until sufficient was present for machining the test bar. In this manner, a tensile strength of 74,000 lbs./in^2 for the weld metal was determined with an elongation of 28.4%.

2. **The Bend Test.**—The bend test shows the average angle which normally can be arrived at lies between 70 and 75°. In many cases, however, if the plate material is of good and uniform quality, capable welders can obtain a bending angle of 180°.

3. **The Impact Test.**—The average value of the weld comes to 9-10. 3kgm/cm^2 and of the plate to 10-12 kgm/cm^2.

4. **Fatigue Test.**—When comparing the values for the high tensile steels with those of the mild steels, it appears that the fatigue strength of the welded joints of high tensile steels lies considerably higher.

MECHANICAL PROPERTIES OF WELDED HIGH TENSILE STEEL

Mechanical Properties	High Tensile Steel A*		High Tensile Steel B*		Weld-metal
	Base Metal	Welded	Base Metal	Welded	
Rockwell hardness	78	82	78	82	82
Yield point in kg/mm^2 in lbs/in^2	37.3	37.5	37.9	37.6	37.7
Tensile strength in kg/mm^2 in lbs/in^2	57.4	55.5	58.1	54.7	52.1
Elongation in %	24.5	....	25.0	....	28.5
Bending angle	180°	90–180°	180°	90–180°	180°
Impact value in kgm/cm^2	11.8	10.6	11.5	10.4	11.0

* See previous table for chemical composition.

Construction Methods for Welded Ships.—In order to arrive at the greatest possible strength and to avoid as far as possible all difficulties, a number of special construction methods have, during the last few years, been developed. These will be briefly described hereunder.

The Trussweld System.—In this construction, the rigidity is obtained by welding angle steels in three perpendicular directions on the junction points. This method is used principally for tank-lighters, pontoons, barges and ferries.

The Channel System.—With this method, the hull consists of connected U-scantlings.

The Reverse Channel System.—Here, the hull is built of U-scantlings but always turn and turn about. In this manner a larger moment of resistance at the same weight is obtained. On the other hand, the ship resistance is also greater and moreover, a larger quantity of welding material is used.

The Lock-Notch System.—In this method longitudinal frames over which knee-shaped cross connections are welded, are used.

Transverse Frame System with Longitudinal Plating.—In this system, the hull construction is practically the same as the normal construction, i.e. transverse frames and fore and aft running plates. Often the longitudinal keelsons are welded to the floor timbers; both parts are then provided with notches.

Transverse Frame System with Transverse Plating.—As formerly difficulties were seen in the welding of longitudinal seams, the longitudinal plating for smaller vessels was replaced by transverse plating.

Spanner System.—According to this method, the frames are welded on separate small legs. This can be arrived at still more simply by a cut-out scantling, which can be obtained by zigzag cutting of high I-beams.

Longitudinal Frame System and Longitudinal Plating.—Here, the longitudinal frame method ("Isherwood" system) is used, while also the fore and aft shell plating is retained.

Pannel System.—By this method, of Dutch origin, the hull is reinforced by longitudinal and transverse frames. The cross frames are notched and the lighter longitudinal frames are welded into these notches.

Hull Flange System.—This system is also of Dutch origin. By this construction the hull is made of a number of relatively small shell-strakes of which every other one is of constant width. Both longitudinal edges of these strakes are flanged in such a way that the strakes of

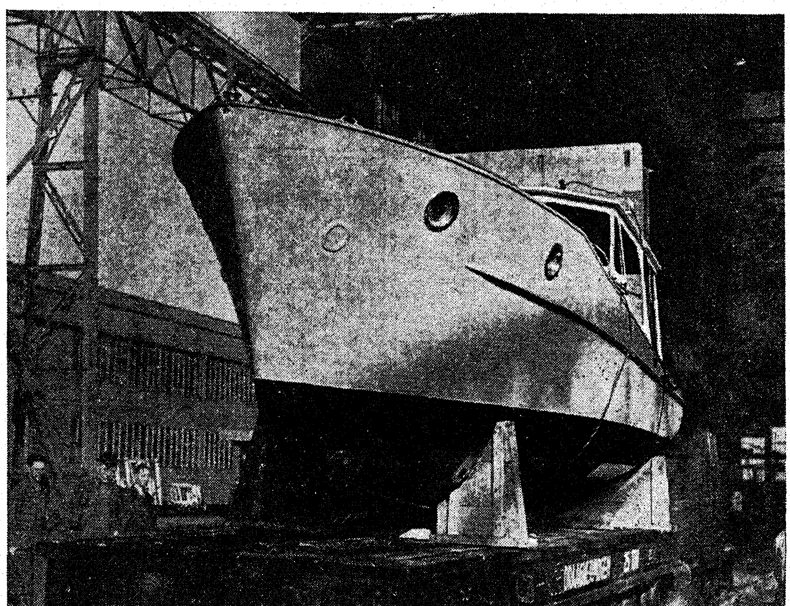


Fig. 5. Motor yacht of arc welded construction.

constant width get an elevated flange and the intermediate of width-deviating strakes, are provided with a lower flange.

In the beginning of 1938 a motor yacht of 8.70 x 2.44 m was entirely welded according to this system. The completed yacht is illustrated in Fig. 5.

The important advantages of this construction method are the limiting of the number of joints and the obtaining of a perfectly smooth exterior of the hull.

A comparative weight and cost calculation taught that in regard to the riveting a wage saving of 110 hours, i.e. 10% of the total, together with a weight economy of 19% could be obtained.

Comparison of Welding Methods.—Fig. 6 gives a view of the total hull surface, the moment of resistance, the moment of inertia and the welding volume for the above discussed construction methods. The

Comparison of welding methods.

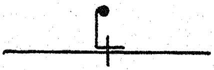
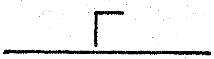
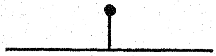
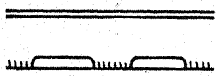
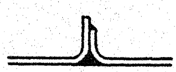
System		Surface in c/m^2	W in c/m^3	I in c/m^4	Welding volume $c/m^3/m^2$
riveted longitudinal frames		89	174	2742	–
Trussweld system		80	186	2940	150
Welded flat bulb		81	180	2560	150
Spanner system		76	186	2340	165
Locknotch system		89	180	3240	155
Channel system		92	89	603	280
Reverse Channel system		92	368	2010	260
Hull-flange system		69	48	563	270

Fig. 6. Total hull surfaces, moments of resistance and inertia, and welding volume for various methods of ship construction.

table shows that the longitudinal frame system gives a minimum weight at a very small welding contents per m^2 hull surface.

Welded Joints in Ship Building.—The welding connections which in external constructions generally are used, are as follows:

I. **Butt-joint.**—(Fig. 7);

a. the V-joint (Fig. 7a). This is the most generally applied and is used up to a plate thickness of about ¾″.

b. the X-joint (Fig. 7b), which is applicable for plates from 5/8" and naturally only for such connections which are accessible on both sides.
c. the scalene X-joint (Fig. 7c). This welding connection tallies with a V-joint which is bevelled on the reverse side and serves to neutralize the shrinkage and distortion which always occur

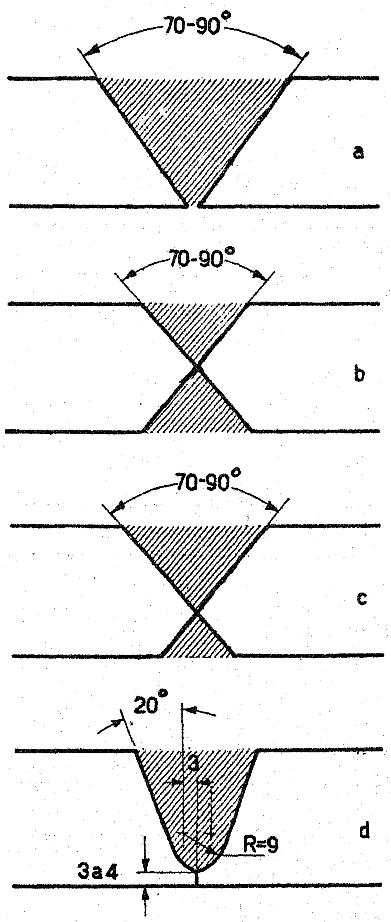


Fig. 7. Various types of butt joints for ship welding.

in a V-weld. With correct preparatory work and a properly made welding, a perfectly smooth connection can be obtained.
d. the U-weld, (Fig. 7d), which is only used for plate above 1" thick and which relatively rarely occurs in shipbuilding.

II. Fillet Welds.—It goes without saying that these welds often occur at all perpendicular connections.

III. T-joints.—(Fig. 8).

a. two-sided fillet-welds (Fig. 8a). These joints are applied mostly by connections with normal static stresses. For constructional parts with dynamic stresses, preference is given to:

b. the K-joints (Fig. 8b). With these, a much better connection is obtained. Up to a plate thickness of 5/8", the body plate is sharply bevelled but for thicker sheet, welds as mentioned under c are used.

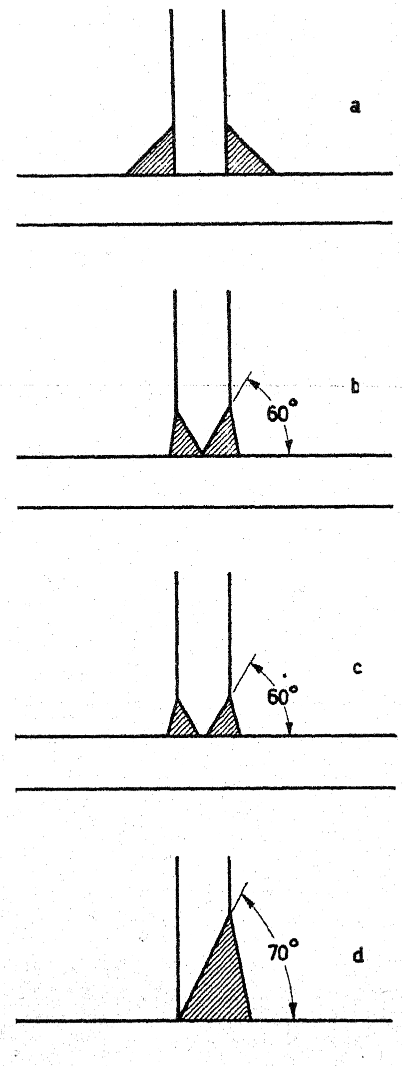


Fig. 8. Various types of tee joints for ship welding.

c. the incomplete K-joints (Fig. 8c) whereby a cleft remains between the plates which is not entirely welded through. The strength of the connections is less than that of the K-joint but still considerably better than the double fillet weld.

It can also happen that the substitution of a double fillet weld by a K-joint causes a crack because the construction becomes too stiff. In such cases cracking could have been entirely avoided by applying an incomplete K-weld (compare Fig. 9), whereby the connection becomes somewhat more supple.

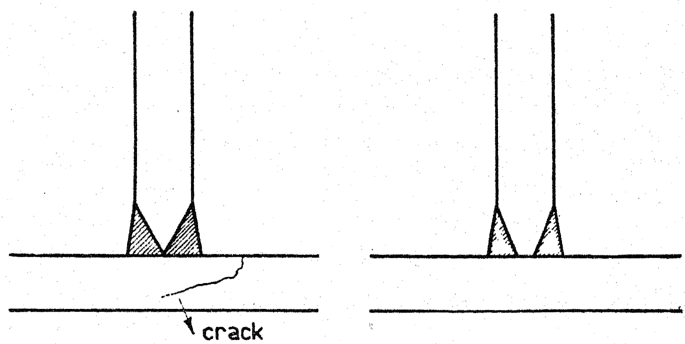


Fig. 9. Incomplete K-weld to relieve stiffness.

d. the half K-joints (Fig. 8d) are used for welds which are not accessible on two sides. It is indeed difficult to get a complete penetration in the root of the angle but nevertheless the strength of the connection is quite sufficient to withstand static as well as dynamic stresses.

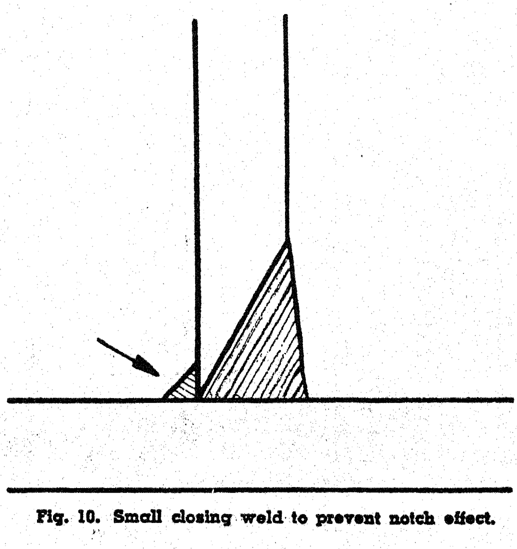


Fig. 10. Small closing weld to prevent notch effect.

In order to prevent rust formation it is advisable to apply a small counter-weld to all lateral welded seams. Even in the case of a half K-joint, where the other side is not so easy of access, an attempt should be made to lay a small closing weld. (Fig. 10). This prevents the notch effect caused by insufficient penetration.

Application of Welding of High Tensile Steel in Naval Construction from 1937 Until Now.—When we compare the application of the welding process in submarine construction in 1933 with that of today, it becomes very clear that in this period important developments in welding of high tensile steels have taken place and which is demonstrated in:

—greater diving depth (to more than 100 m.).
—heavier armaments.

In order to properly grasp the importance of the welding process it is also desirable to examine the construction of a submarine.

Such a ship consists of a cylindrical part which has to absorb the underwater pressure. Around these cylinders there are tanks which by means of large valves placed underneath can be filled quickly, whereby the buoyancy of the ship is destroyed and with the aid of propellers and rudders she then can dive and continue to proceed submerged. The outside of these side tanks consists of a shell-plating which may be thin, because apart from very exceptional circumstances, the water pressure on both sides of this outside hull is equal as the kingstones remain open. By means of large air-exhaust valves on top of these side tanks a quick filling-up is aided as much as possible.

The cylindrical pressure body is cut off underneath by the double

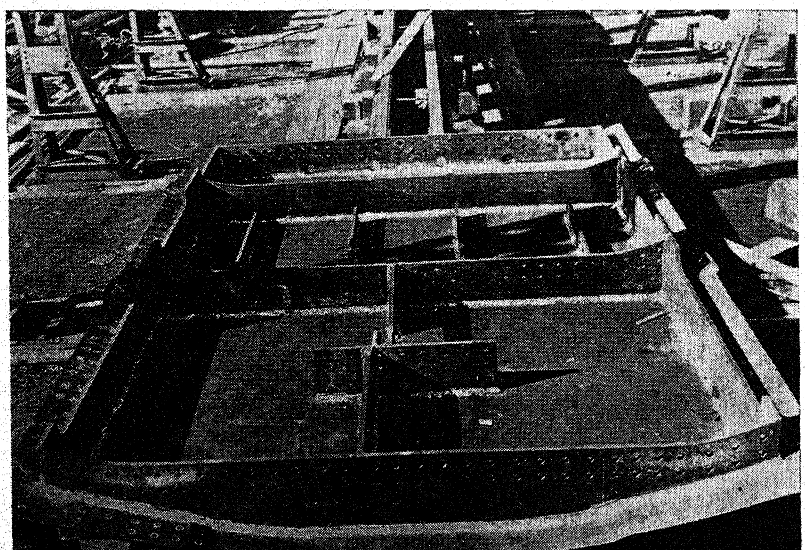


Fig. 11. Arc welded kingstone plate.

bottom plating under which the various oil- and water-tanks are situated.

In many submarines, the double hull-system at the ends of the boat goes over to the single hull construction, as otherwise the two hulls would come too close to each other, which would not only be difficult to construct but would also be hard to conserve. At the ends, therefore, we have a pressure-body of which the section is no longer cylindrical but more closely resembles the ordinary ship shape. The consequences are that the fore and aft frames are heavily stressed on bending and therefore must be strongly constructed.

A welded kingstone-plate is reproduced in Fig. 11; the holes have here still to be introduced.

In the double bottom and in the horizontal keel-plate the butt joints are entirely welded. These seams have been welded partly in the workshop and partly on board. All oil- and water-tight floor-timbers (Fig. 12) in the double bottom are also entirely electrically welded; this welding is all done in the workshop. In Fig. 13 a double bottom section is reproduced which shows the lower edge of the double bottom plating. These sections are transported to the slip-way, (Fig. 14), and attached to the horizontal keel plate.

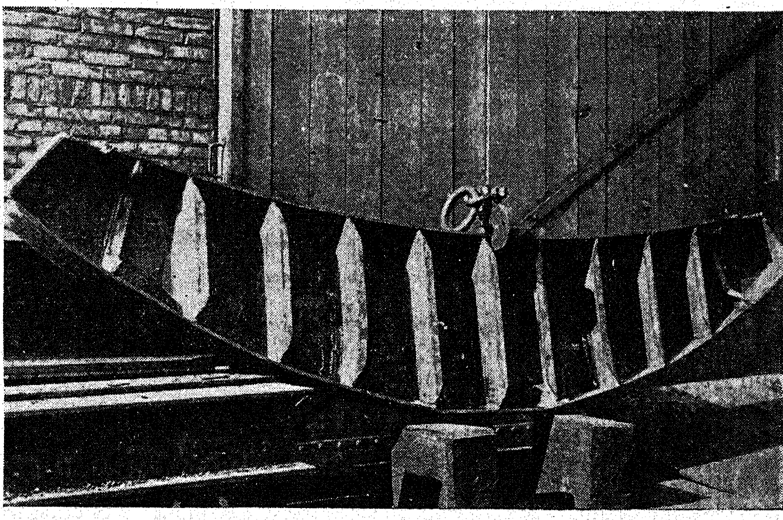


Fig. 12. Arc welded floor timber.

In the now-building submarine minelayers, the connection of the horizontal keel-plate to the first sheer-strake is entirely welded. These seams are entirely welded in the workshop.

The unequal sided X-weld for the connection of the margin-plate to the angle steel is entirely finished in the workshop. The longitudinal V-seam for the connection of the double bottom to the inner-hull, is entirely welded on board. After this V-weld was put in place the connection was riveted to the inner-hull. This is one of the points where diffi-

culties with regard to the proper method of packing occurs but which can be entirely solved by the use of asbestos stoppers.

The seams and butt-joints in the compression cylinder were partly welded in the shop and partly on board. For this connection a V-joint with re-welding strip was used; the strip is only then added when the root of the V-weld is chipped away and re-welded.

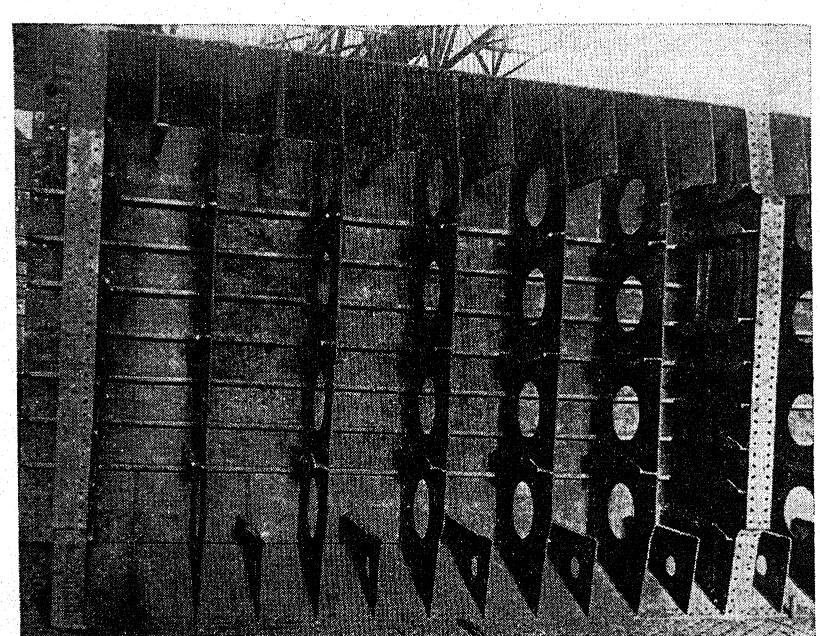


Fig. 13. Arc welded double bottom section.

A very difficult and, therefore, most interesting welded construction which has only been used lately, is that of the frames in the forecastle and after body of the ship. Due to the oval shape of the frames considerable bending moments occur. As the required moment of resistance increases, the height of the frame becomes greater and the inner bunt-lines heavier. Each of these frames is carefully calculated so that each section could be exactly determined.

Through welding, a very considerable weight economy was obtained as hereby it became possible to bring the frame section in accordance with the occurring stresses, with a consequent better division of material. When welding the frames, an additional complication arises because the outer flanges do not stand perpendicular on the body plate. The flange plate must follow entirely the bevel of the hull. Because of this it is necessary to let the body plate form an ever-changing angle of deviation of 90° on different points and frames.

In Fig. 15 a section of a part of the frame is illustrated and shows how the connections between body and flange plates have been made.

As the welded frame was used for the first time and we therefore

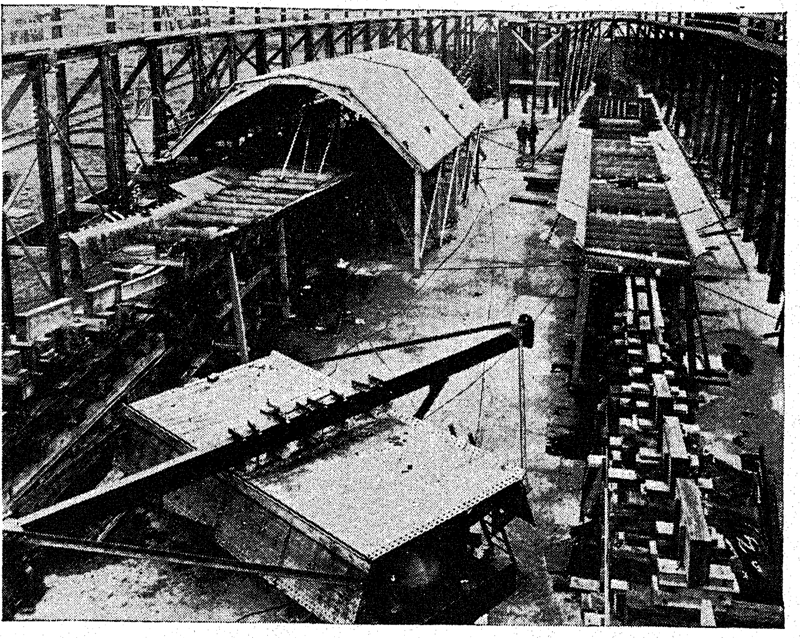


Fig. 14. Placing shop welded sections on horizontal keel plate.

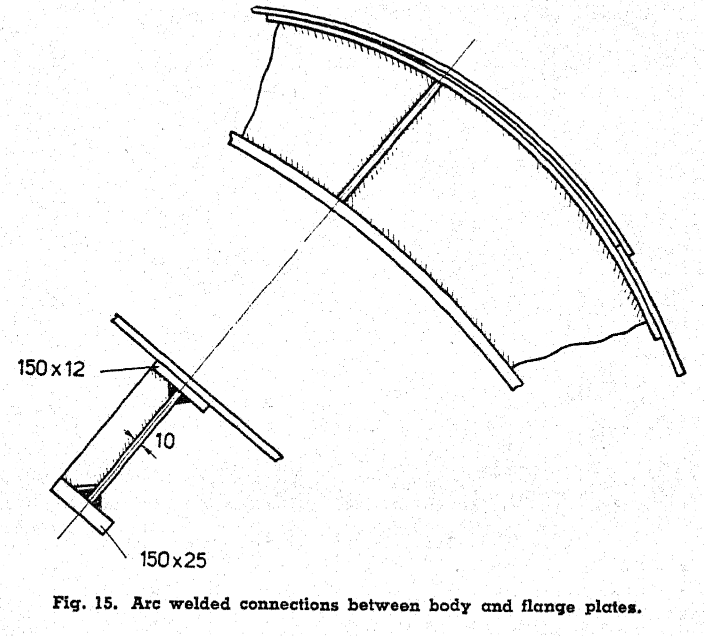


Fig. 15. Arc welded connections between body and flange plates.

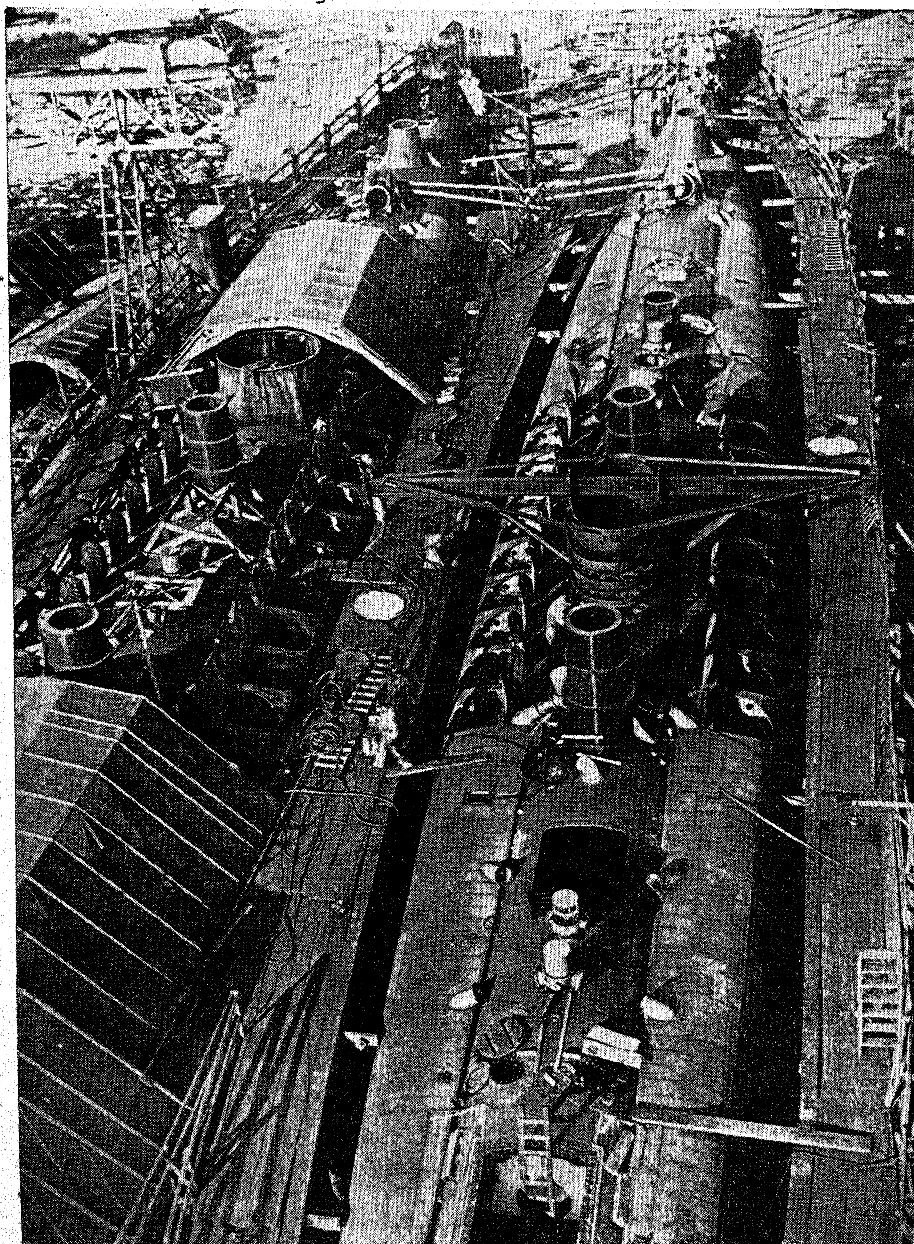


Fig. 16. Submarine mine layers under construction.

could not rely on previous experience, greatest care was taken in determining the welding method.

The shearing stresses on the seams were calculated according to the table of Prof. Dustin, wherein is indicated, that at a shearing stress above 2800 kg/cm^2 (40,000 lbs./in^2) fracture occurs. As it was desirable to be perfectly certain with regard to the allowable stresses of the welding seam on shearing, separate tests were made.

An investigation on a bended frame produced too many difficulties. Therefore a straight welded small beam was constructed. Welding seams were introduced in the center of the body plate, the point where the greatest longitudinal shearing stresses occur. This beam was stressed by two hydraulic presses which worked on one pump. The bending and shearing stresses were calculated in advance for various loads. During

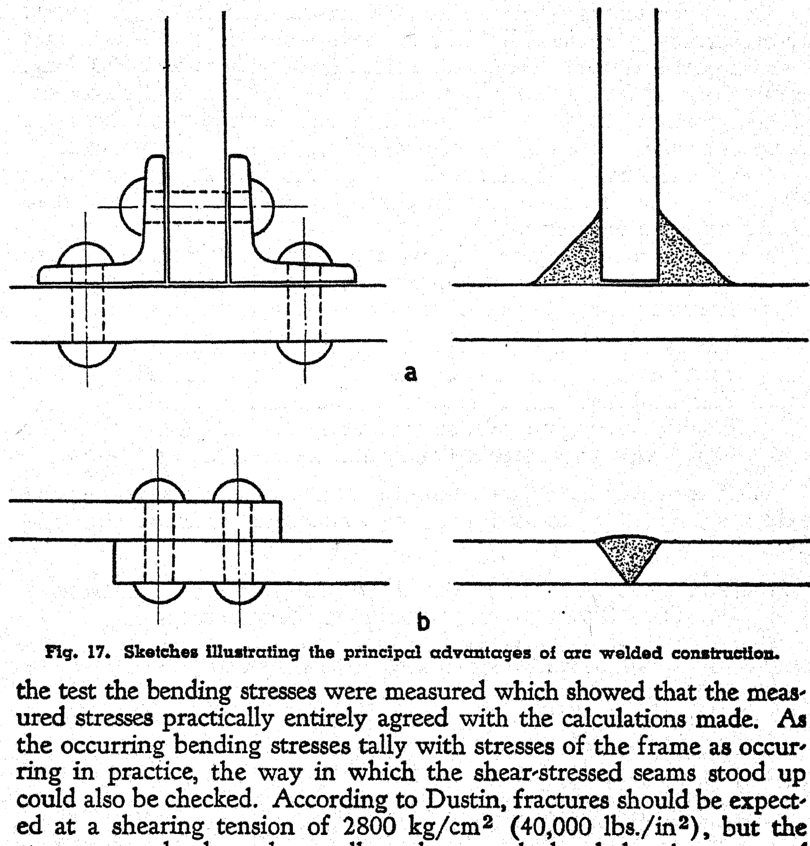


Fig. 17. Sketches illustrating the principal advantages of arc welded construction.

the test the bending stresses were measured which showed that the measured stresses practically entirely agreed with the calculations made. As the occurring bending stresses tally with stresses of the frame as occurring in practice, the way in which the shear-stressed seams stood up could also be checked. According to Dustin, fractures should be expected at a shearing tension of 2800 kg/cm^2 (40,000 lbs./in^2), but the stress test only showed a small crack at a calculated shearing stress of 3960 kg/cm^2 (55,500 lbs./in^2) or a 35% greater stress. The test was continued up to a stress of the beam past the yield-point. After tremendous distortion the weld remained completely intact. The small crack which occurred at a stress of 3960 kg/cm^2 had not become larger at all.

Many other important parts, like engine beds, gun foundations, water-tight bulk-heads between inner- and outer-hull, the shaft-bosses and machine gun bores, the small ballast partitions on the horizontal keel-plate and the torpedo loading head, were all electrically welded. We might reiterate that all these parts are made of high tensile steel.

Fig. 16 gives a birdseye view of the two submarine minelayers in February 1938.

Economies Obtained in Consequence of the Welding Process.—The principal advantages of welding in regard to riveting, are demonstrated by Fig. 17, a and b: the elimination of angle steels and overlapping.

This really is the gist of the saving which is obtained through electric welding, a saving in material which in the first place gives a considerable saving in weight next to a cost economy.

On smaller vessels, where the flange percentage and the weight caused by overlapping are relatively high, this saving in weight will be greater than on ocean steamers. For an all-welded small tanker about 130′ long, the total saving in weight comes to about 30%, for a welded cargo-boat of 250′ to about 12.5%. At the same time, engine weight and fuel stock becomes smaller while displacement decreases by some percentages.

Next to the cost of material, the wage costs also play an important rôle and it is interesting to see how the work- and wage-hours compare on riveting and welding jobs.

If we examine the entire ship, we can approximately trace the proportion in which the various connection groups occur. This estimate, which naturally is fairly rough, gives the following results:

Seams	50%
Butt-joints	15%
Frames, beams, stays	25%
Connection angle steels, single	5%
Connection angle steels, double	5%

With the aid of these data we can then calculate the average quantity weld metal for all joints taken over the whole ship, which replaces one rivet.

AVERAGE QUANTITY WELD METAL (IN CM³) WHICH REPLACES ONE RIVET BY VARIOUS PLATE THICKNESSES

Plate Thickness	Average Quantity Weld metal
4 mm	1.22 cm³
5 "	1.62 "
6 "	2.22 "
7 "	2.94 "
8 "	3.37 "
9 "	5.04 "
10 "	5.40 "
11 "	5.48 "
12 "	5.73 "
13 "	6.77 "
14 "	7.90 "
15 "	8.84 "
16 "	10.71 "

Now, it is known from experience how many rivets per ton steel weight are used in ships of different types and sizes. Thus, the total number of rivets per ship can also be worked out.

The work is done in shifts and out of the number of rivets per shift and the number of shift hours, the total number of riveting hours can be calculated.

TOTAL RIVETING TIME FOR SHIPS OF VARIOUS TONNAGE (CARGO-BOATS)

Steel Weight in Tons	Number of Rivets per Ton	Total Number of Rivets	Total Riveting Time in Hours
1,000	270	270,000	24,800
2,000	220	440,000	47,000
3,000	215	645,000	72,000
4,000	215	860,000	105,000
5,000	215	1,125,000	140,000
6,000	215	1,290,000	168,000
7,000	218	1,484,000	200,000

Furthermore from experience and calculations, the average rivet diameter for ships of different sizes is known. From this the average plate thickness can be calculated and from this again the average quantity weld metal which replaces one rivet.

AVERAGE RIVET DIAMETER, PLATE THICKNESS AND AMOUNT OF WELD METAL FOR SHIPS OF VARIOUS STEEL WEIGHT (CARGO-BOATS)

Net Steel Weight in Tons	Average Rivet Diameter in mm	Average Plate Thickness	Average Quantity Weld metal
1,000	17.0	8.5 mm	4.3 cm^3
2,000	18.5	11 "	5.5 "
3,000	19.5	12 "	5.8 "
4,000	20.5	13 "	6.7 "
5,000	21.5	14 "	7.6 "
6,000	22.0	15.5 "	9.6 "
7,000	22.3	17 "	12.2 "

We now, therefore, know:

a = the quantity welding material which replaces one rivet.
b = the number of rivets per ton steel and it can be worked out that:

quantity weld metal per ton steel weight = number of rivets per ton x quantity weld metal per rivet.

We also know from experience, the average amount of weld metal which per hour and by various plate thicknesses is in practice deposited so that we are able to calculate the total welding time for ships of various tonnage. The results of these calculations have been collected in the following table.

TOTAL QUANTITY OF DEPOSITED METAL AND TOTAL WELDING TIME FOR SHIPS OF DIFFERENT TONNAGE (CARGO-BOATS)

Steel Weight in Tons	Deposited Metal per Hour	Weld Metal per Ton Steel Weight	Total Welding Time for Entire Ship
1,000	40.0 cm^3/h	1,180 cm^3	29,500 hrs.
2,000	48.0 "	1,200 "	50,000 "
3,000	52.0 "	1,270 "	71,400 "
4,000	55.0 "	1,440 "	105,000 "
5,000	57.0 "	1,625 "	135,000 "
6,000	59.5 "	2,040 "	202,000 "
7,000	61.2 "	2,800 "	320,000 "

General Economy and Advantage of Welding of High Tensile Steel (Commercial Ship Building).—In order to get an idea of the advantages offered by the use of high tensile steel a check has been made of the economies obtained in the case of a ship where the welding process has already been extensively used.

For a passenger steamer of 40,000-ton displacement, 1500 tons high tensile steel material can be used. In connection with the higher yield point a reduction of the scantlings of 20% is fully justified so that simply replacing mild steel with high tensile steel, gives a weight saving of 300 tons which can still be increased to 370 tons if the welding process is used. This means an extra increase of the dead weight capacity by ± 2%, an advantage which repeats itself at every trip and represents a considerable amount over the whole life of a ship, usually from 15 to 20 years. Even if the price of high tensile steel is higher and the cost of welding somewhat greater than riveting, the use of a welded high tensile steel construction will show a financial advantage as the greater dead weight capacity will yield favourable financial results.

It is also possible to let the ship keep her same dead weight capacity, so that the displacement can become ± 1% smaller. This means for the service-speed a saving in power of at least 300 h.p. which will show a yearly saving in fuel of Fl. 18000,—($10,000).

To this must still be added the savings in costs consequent on the lower harbour and piloting fees because of the smaller displacement and, therefore, smaller tonnage.

Naval Construction.—In war ships, cruisers, torpedo destroyers, and submarines, where the question of costs plays a much lesser rôle, the weight and space saving is the most important factor.

The weight economies obtained through welding of the hull, the double bottom, the watertight bulkheads, the foundations, and numerous other parts of high tensile steel, means for a submarine of about 1000-ton surface displacement a weight decrease of certainly 65 tons, whereby, the fuel stock and armaments can be considerably enlarged. If for some reason or other this is not possible or required, the saving in weight can be used to increase the ballast in which case a ship of the above-mentioned dimensions could have the metracentric height increased by no less than 4 inches.

The great advantage of the use of high tensile steel becomes still more striking, when we see that by not increasing the dimensions in regard to those of mild steel but by keeping them equal, the diving depth for a boat of 1000-ton surface displacement can be increased by certainly 30 to 40%.

When these economies are divided over diverse factors, the ship mentioned could benefit by the following improvements:

1. 50′ greater diving depth (15 tons).
2. 2″ greater metracentric height (20 tons).
3. More ammunition and torpedos (5 tons).
4. Heavier anti-aircraft guns (4 tons).
5. Larger diesel engines, therefore greater surface-speed (8 tons).
6. A larger storage battery, therefore greater submerged speed (9 tons).
7. More fuel and lubricating oil, therefore greater operating radius (4 tons).

These savings in weight can naturally be divided differently or applied to one or two of the above mentioned improvements, but this division is given in order to give an impression as to which advantages the applications of electric welding and high tensile steel can produce.

Part of the savings can also be sacrificed in order to increase the safety coefficiency of the compression-strength of the hull, so that the official diving depth can in case of distress be exceeded to a greater extent than formerly, when the hull was made of riveted mild steel.

In torpedo destroyers, the weight savings obtained will be largely utilized to increase the speed and radius of action. Although for these ships high tensile steel has been used for a considerable time, the application of electric welding gives a savings in weight of about 3% of the displacement or 45 tons. The armament, engine equipment or fuel stock can to this extent be increased or the speed further augmented.

The data given in the following table show the savings available.

ECONOMY OF WELDING AND THE USE OF HIGH TENSILE STEEL

Structural Part	Welding Against Riveting		Welded High Tensile Steel Against Riveted Mild Steel	
	Saving in Weight	Saving in Cost	Saving in Weight	Saving in Cost
Shell and Deckplating	9%	8%	20.8%	8.3%
Double Bottom	23.5″	20.2″	33.3″	7.0″
Flat Bulkheads	18.0″	12.3″	34.5″	9.5″
Concave Bulkheads	8.6″	3.6″	32.8″	11.7″
Engine Foundation	15.9″	12.7″	32.7″	2.5″

Summary.—We can express the total economies through use of arc welded high tensile steel in ship construction by two degrees of comparison, namely,

a. economies obtained by welding with respect to riveting.
b. economies obtained by the use of high tensile steel with respect to mild steel; these savings become still more obvious, if in this instance the welded construction in high tensile steel is compared with the riveted construction in mild steel.

It is clear that welding in comparison with riveting shows a remarkable saving in weight and cost, but in comparing welded high tensile steel with riveted mild steel, the weight economy is still more accentuated. The saving in cost however, because of the higher price of high tensile steel, is somewhat smaller.

The weight economies are not only of the greatest importance to commercial vessels but also to battle ships and it may be expected that the application of the electric welding process itself and more especially the welding of high tensile steels shall in the near future develop more and more. The authors sincerely hope that their study has contributed to this development.

Chapter II—A Modern Type of Welded Deck Barge

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In order that the design of any structure be economical it must of necessity embody the following features:

a.—Suitability for the work it is designed to perform.

b.—Sound structural design.

c.—Economical in its welding technique.

d.—Attractive in first cost and economical in operation.

The welded barge herein described is developed with the intention of fulfilling the above conditions.

The design calls for an all welded steel barge, (see Fig. 1), of 1,000 tons capacity, of rugged construction to withstand rough handling to which such barges are subjected in service. The design has been reduced to the simplest form. Wide plates, now readily available from the steel mills, are used wherever possible to reduce the number of joints.

All frames are built up from rolled flats and bars. Standard structural shapes are used for joining the various members and for re-enforcing flat unsupported plate sections. The strength of bulkhead stiffeners has been improved by welding toe of angle bar to plating, producing results similar to those of Z bars. Curved plates and shapes have been reduced to a minimum.

All material entering into this structure is ordered from the steel mill, sheared to size, allowing for the usual established tolerance. The design in turn makes due allowance for these slight variations in width and length. In addition, the schedule of material as furnished the mill, lists each item by number, making identification at point of delivery readily possible.

The general features of the design make possible the construction of this type of barge at any shipyard. The equipment required is comparatively small, as all material has been cut to proper size at the steel mill, and fabrication of the barge is reduced to assembly of parts, welding of sections, erection on ways and welding of sections together.

It is to be noted that simplicity of design is of paramount importance. Wherever possible, complicated connections, curved or bent plates and shapes have been reduced to a minimum, yet the general appearance of the barge and its utility do not suffer.

The method of fabrication reduces handling charges. Welded sections are kept within certain weight limits, not to exceed crane capacity.

By this method, overhead charges, being dependent on the initial cost of plant equipment and cost of supervision, are kept within economic limits.

The barge, designed to meet the rules and regulations of the American Bureau of Shipping, is of the following general dimensions:

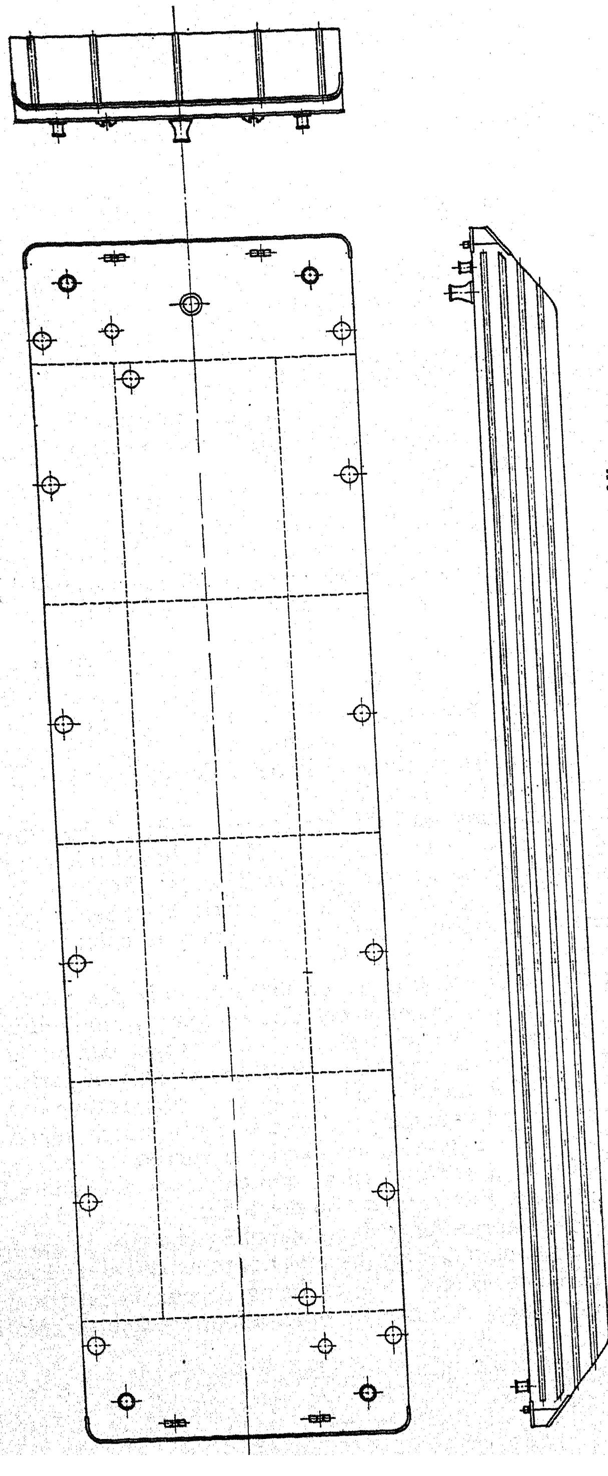


Fig. 1. General outlines of barge designed for arc welding.

General Dimensions of Barge

Length over all	150′—0″
Beam	40′—0″
Width over fender	40′—2½″
Depth amidship	10′—6″
Depth at sides	10′—3″

By the use of water tight bulkheads, the barge is subdivided into 11 compartments. This will enable the barge to stay afloat with one or more compartments flooded.

While the design, as presented, calls for a bare deck barge, its construction is such that it lends itself readily for carrying cargo below decks by the addition of a cargo hatch in deck and floor in center compartments. Such items as deck house, railings, deck bulkheads, etc., have been purposely left off, as they are usually supplied to meet each individual owner's ideas.

This design of barge can also be adapted for liquid cargo below decks, or a combination of dry deck cargo and liquid cargo below deck.

In service, this type of barge is quite economical. Welded seams are permanently water tight and require no upkeep. They corrode no more than steel plates. All welded joints are rigid; they prevent corrosion, as paint does not crack in way of joints.

The absence of holes and rivets eliminates, to a large extent, damages in operation.

Major repairs are accomplished by cutting out the damaged parts, fitting and welding in new parts, with the least amount of delay.

Should such a barge become seriously damaged, it can be beached and repaired at any convenient location, portable cutting and welding machines being transported to the location of barge.

Reduction in weight over any other construction represents increase in carrying capacity.

The design of this barge is so developed, (See Fig. 2), as to enable any small shipyard to produce an economical unit with the least amount of labor and overhead expense. The various parts of the structure are built up of plates, bars and shapes, of standard commercial size, of such dimensions to eliminate extras due to special sizes, or the requirement of special rolling equipment. Such material will also be available from any steel mill at short delivery notice.

The material schedule prepared from the design, calls for all plates and bars to be sheared to size, subject to standard tolerances. The shapes are ordered to length. Any bent shapes and plates are ordered from sketches, to be fabricated at the steel mill proper or at a plant connected with the steel mill, so that all material entering into the construction of the barge is ready for assembly at the shipyard, immediately upon its arrival from the steel mill.

Any bent shapes or plates are usually ordered with extra length, to allow for adjustments during erection. All material is ordered from the mill subject to inspection by classification society, the surfaces to be oiled to prevent surface corrosion, no painting to be allowed. Following this method of procedure, it is evident that the amount of equipment at the shipyard can be reduced to a minimum.

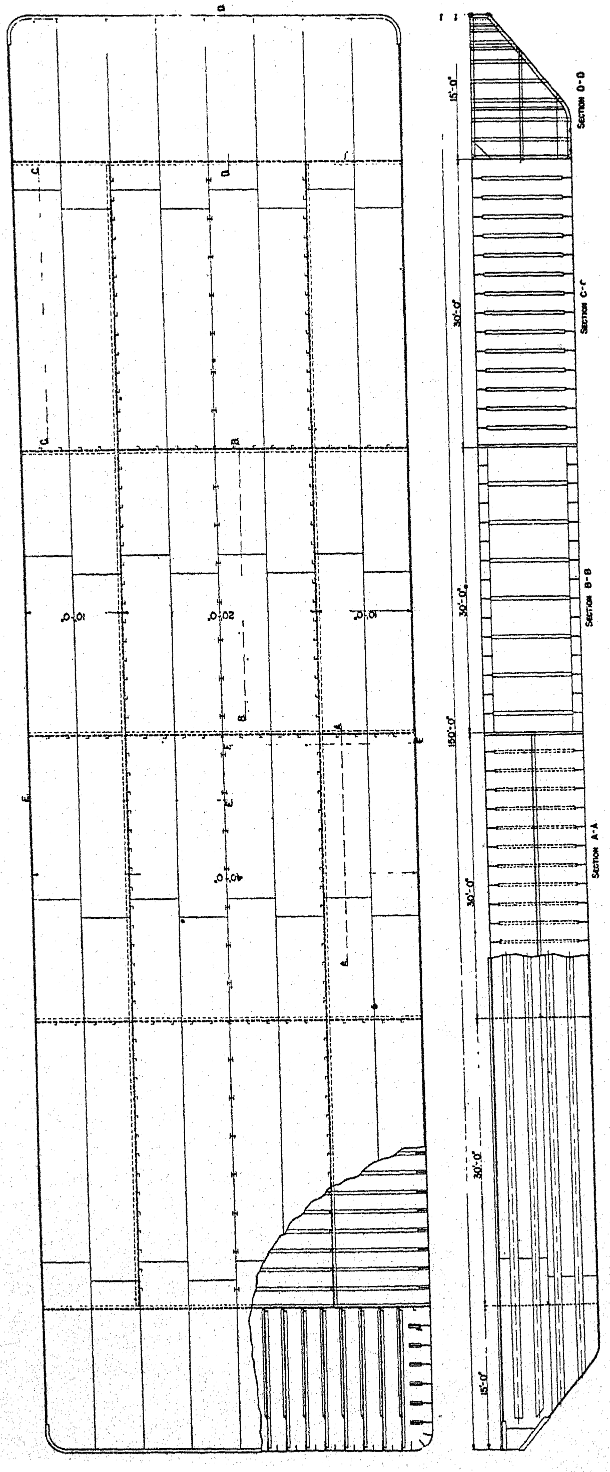


Fig. 2. Arrangement of arc welded deck barge.

As the material arrives at the plant it is removed from the cars by a locomotive crane and delivered direct to the fabricating shop. Necessary blocking is provided to facilitate handling during the various fabrication operations.

In case any cutting of plates and shapes becomes necessary, gas or arc cutting equipment is provided.

It is to be noted that all parts of this structure are fabricated and erected without using erection bolts. This eliminates drilling of holes. Suitable dogs and wedges will be provided for temporary securing of plates and shapes. In addition, an air compressor unit with air hose and chipping hammers forms part of the plant equipment.

Deck fittings such as bitts, chocks, etc., are fabricated by welding from pipes, plates, bars and shapes, as the case may be. This eliminates costly patterns and trouble with castings.

In case a number of identical fittings are required, jigs are prepared to make all parts interchangeable; this will also further reduce unit cost.

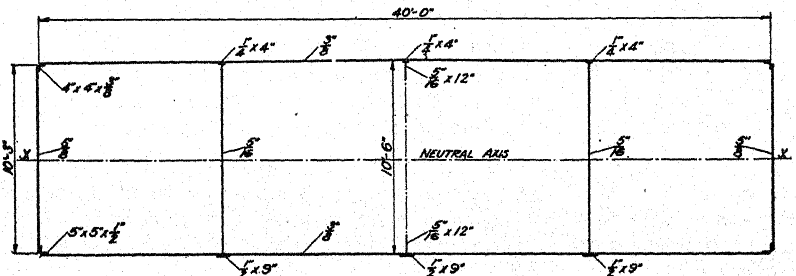
The material entering into the construction of this barge consists of the following:

Summary of Material Weights and Cost

		Cost delivered
Bottom plating	105,000 lbs.	$ 2,480.00
Side plating	85,000 lbs.	2,168.00
Deck plating	91,000 lbs.	2,320.00
Bulkheads	58,700 lbs.	1,500.00
Frames	83,070 lbs.	2,120.00
Keel plates and fenders	31,780 lbs.	810.00
Angles and flat bars	35,390 lbs.	892.00
Columns	4,500 lbs.	1,140.00
Deck fittings	4,820 lbs.	870.00
Paint, etc.	4,000 lbs.	625.00
Welding Wire (included in above weights.)		350.00
Total	503,260 lbs.	$15,275.00

Note.—All prices based on quotations dated May 1938.

Welded Fabrication.—It is not the object here to specify any particular type or make of arc welding machine; furthermore it is assumed



Net Area=632.0 Sq. Inches

Fig. 3. Net cross section of barge.

that a qualified organization of welders is available, with experience in similar or allied industries and that such organization members have been qualified by the classification society, under whose rules and regulations this barge is to be built.

The welding as here applied is comparatively simple, with overhead welding reduced to a minimum.

Welding in Fabricating Shop.—All steel plating, bottom, sides and deck, is assembled in sections, by lining up two adjacent plates on suitable blocks in a horizontal position, leaving a uniform gap depending on plate thickness.

Thickness of plate	Gap between plates
1/4″	5/16″
5/16″	7/16″
3/8″	1/2″
7/16″	9/16″
1/2″	5/8″
9/16″	11/16″
5/8″	3/4″

It is to be noted that in case the plates are sheared at the mill with plus tolerances, the sections so spaced will become wider than called for. In case the tolerance is minus, the sections will be narrower. The design takes care of these deviations as the overlap of plates on corner angles on the outside, and overlap on keel plates on the inside, will allow for a comparatively wide variation, without in any way affecting the strength or suitability of the completed welded structure.

The angle stiffener or backing-up member is now positioned over the space between the adjacent plates and tack welded in position, using a 1″ weld spaced about 24″ apart, alternating between heel and toe.

The two plates with the angle bar now form one section and are turned over on the blocks 180°, leaving the gap between the two plates on the upper side free for down-welding of the longitudinal water tight seam. This weld is a very important factor, as in addition to being water tight it is also a strength weld, upon which the success or failure of the whole welded construction rests. The method of producing this joint is as follows:

1. The two edges are welded to backing-up angle by a fillet weld, one on each side.
2. The two fillet welds are now well wire brushed.
3. The space between the two fillet welds is now bridged over by a third weld in such a manner as to allow for a reasonable re-enforcing portion, extending beyond the plate thickness.

This method is recommended for the following reason:

Fillet welds are known to be most efficient and due to their simplicity are easily applied. The filling-in weld is important as it brings the oxidized surfaces and any impurities left in the two fillet welds to the surface of the filler weld, where it will finally accumulate on the top surface of the finished weld, forming a crustation as re-enforced portion of weld, helping to counteract corrosive action.

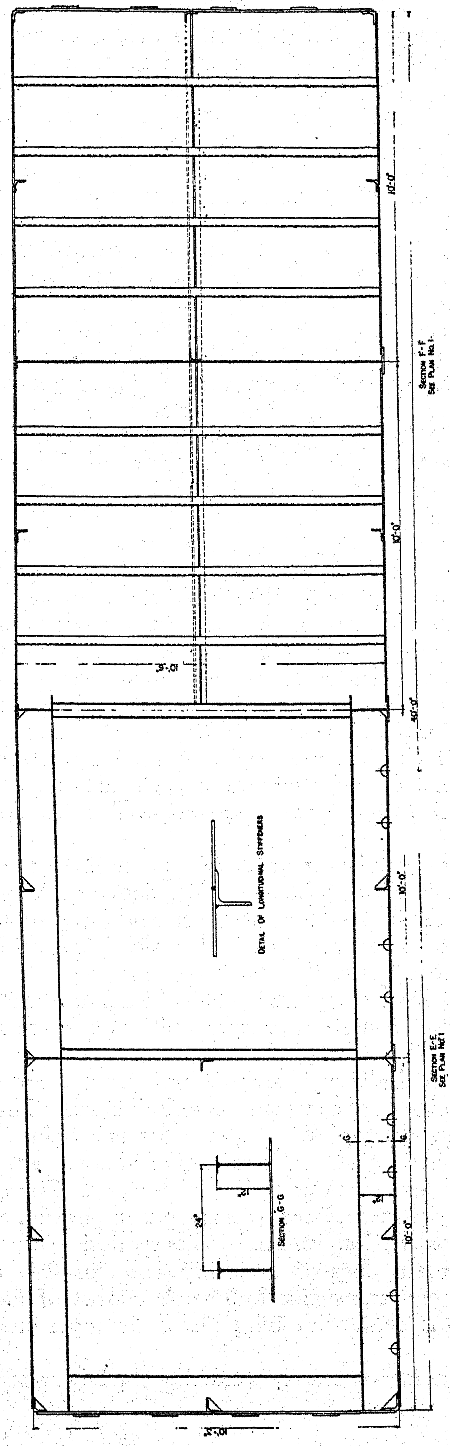


Fig. 4. Arc welded barge design—transverse sections.

In addition, the application of a filler weld over the two fillet welds has a tendency to anneal the latter and remove excessive stresses.

After the longitudinal seam has been completely welded, the section is again turned over 180°. The transverse frames, (See Fig. 4), are now located in position and tack welded at each end to the section to prevent dislocation, after which the frames are intermittent-welded, using a 2″ weld and 4″ space, located alternate from one side of the frame to the other.

As will be seen from the plans, the construction of sides and deck sections is in all respects similar to that of the bottom sections and the same welding procedure will apply.

The frames consist of hot rolled flats to which is welded on top a strip to form a T section. The fillet weld, securing strip to flats is of the intermittent type, 2″ weld with 4″ space, placed alternate on each side to prevent warping. The frames are notched by gas cutting to clear longitudinal stiffeners of sections. Corners at the ends are cut diagonally to clear corner angles on one side and bulkhead or intercostal girder at the other. Notches and diagonal cuts at the ends also serve as drains on the bottom frames.

Bulkheads, (See Fig. 5), are built up of flat plates, the horizontal joints are backed up by an angle bar, similar in all respects to the joint as described for shell plating. The bulkhead stiffeners, arranged vertically and spaced as shown on plan, consist of angle bars, arranged toe to plating. This position of angle bars affords greater strength, as each angle in conjunction with bulkhead plating represents a Z section.

The angle bars after being located on the bulkhead sections, while in a horizontal position, are tack welded at each end to prevent dislocation, after which they are finally secured by intermittent welds, 2″ weld, 4″ space, arranged alternate on each side of angle flange. This construction applies to the transverse as well as to the longitudinal bulkheads.

The transverse bulkheads are made up in 3 sections each. The wing sections are welded to bottom, side, deck and longitudinal bulkhead, the center sections to bottom, deck and longitudinal bulkheads. After being located they are first tack welded in position, 1″ welds spaced about 3 feet apart.

They are now ready for final welds, either intermittent 2″ weld and 4″ space in case of non-water tight bulkheads, or continuous welds for water tight bulkheads.

The longitudinal bulkheads are preferably made up in one section to cover the distance between transverse bulkheads. The lower edges rest on keel plates, the top edges have a flat bar welded as shown on plan, using intermittent fillet welds in case of non-water tight bulkheads and full welds in case of water tight construction. These top bars act as a landing place when deck sections are put in position and as a backing-up member for the longitudinal joints in deck plating.

Intercostal girders, located amidship and forming a continuous member between end transverse bulkheads consist of flats, the lower one being secured to center-line bilge plate, the upper one carries a bar on top.

Both girders are intermittently welded to the bilge plate and top bar,

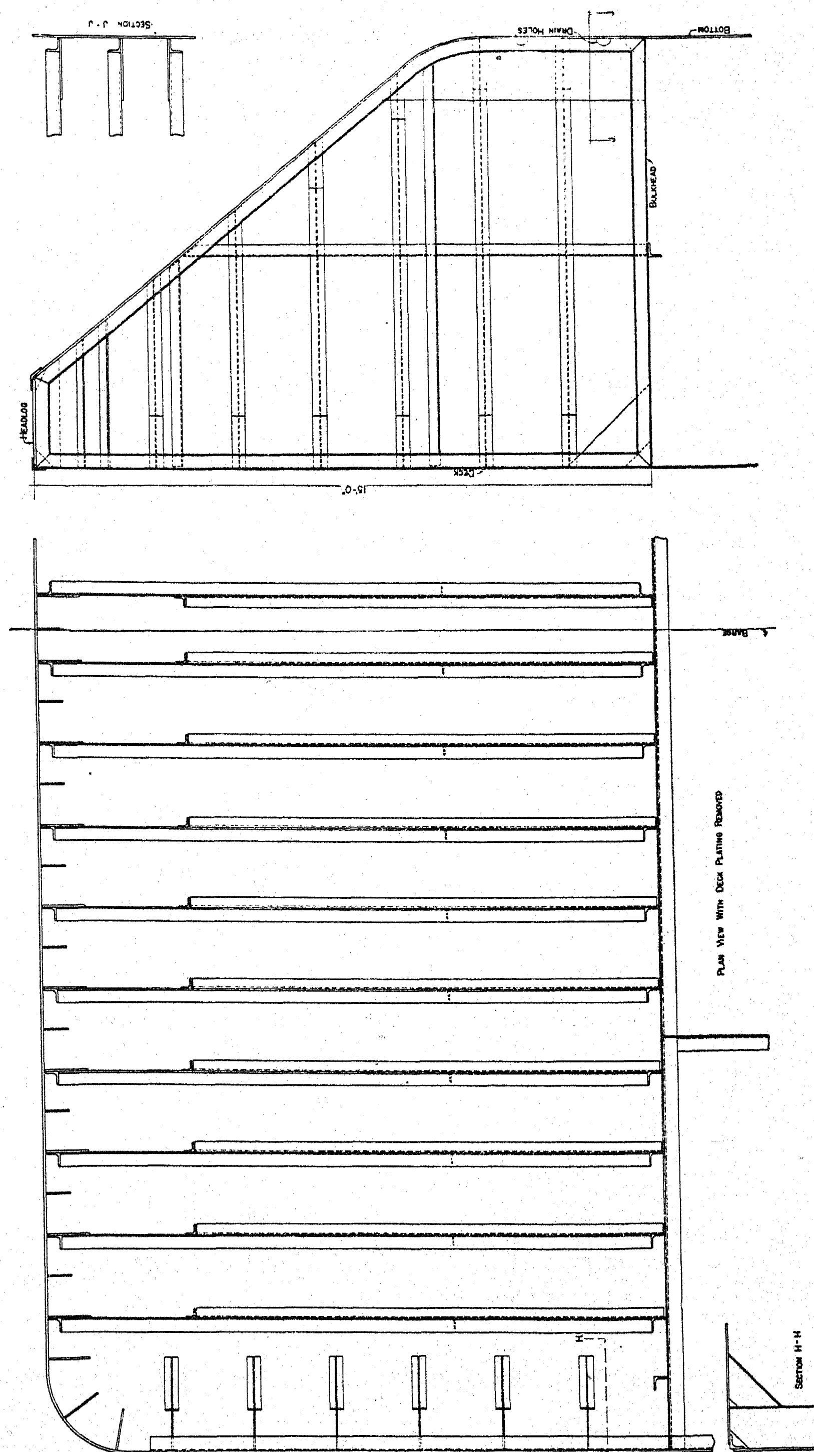


Fig. 5. Barge end.

respectively, 2″ welds, 4″ spacing, arranged alternate from one side to the other. The bar of top girder acts as a landing place for deck sections and as a backing-up member for the longitudinal joint in the deck plating. Ends of transverse frames, deck and bottom are intermittently welded to girders, 2″ weld, 4″ space.

Keel plates are welded to one section of bottom, first tack welded from the inside, 1″ weld spaced about 36″ apart and after section is turned over, a full fillet weld is applied securing outer edge to bottom plating. Bottom corner angle is similarly welded to end of side bottom section.

Angle bar frames of end sections are first assembled with corner, end and bottom brackets secured by intermittent welds. In addition, each frame has one vertical and one horizontal angle bar member, secured by intermittent or continuous welds to angle bar frame and bottom brackets respectively.

The assembled frames of end sections, spaced as shown in Fig. 5, are first positioned by tack welds, 1″ weld, spaced about 36″ to bottom plating, end transverse bulkhead, deck plating and headlog plate and afterwards finally welded by intermittent welds, 2″ weld and 4″ space. All angle bar frames are arranged toe to plate for greater strength as shown.

Side frames of end sections, located and spaced as shown on plan, consist of flats to which is welded on top a strip, to form a T section; in all respects similar to frames of main body.

These frames are positioned to sides of end sections by tack welds, 1″ welds spaced about 36″, and afterward intermittently welded to side plating, 2″ weld and 4″ space.

Single flats, located in way of rounded corners at ends are secured by intermittent welds similar to the other side frames.

Welding at the launching ways.—After the various sections of the barge have been assembled and welded in the fabricating shop, they are transported to the launching ways and erected.

As each section is located, it is ready for welding to the next adjacent section as follows:

After end section of bottom has been placed in position, the side section is erected and temporarily shored. In this position, bottom corner angle is first tack-welded on the inside to side plate and afterward bottom end of side plate is welded to angle on the outside by a continuous fillet weld. In addition, flat of side frame is welded to bar of bottom frame by intermittent welds, 2″ weld and 4″ space. This makes each frame a continuous rectangular member, consisting of bottom, two sides and deck frame.

The other end of bottom section, with one end of keel plate already welded, receives the longitudinal bulkhead section, which is welded to keel plate by a continuous fillet weld.

The end section of frame is also welded to bulkhead by intermittent welds.

Assuming that the inside bottom section is next put in position, the end plate is tack welded to keel plate from the inside and afterwards the edge of keel plate is welded to bottom plate on the outside, by a full

continuous fillet weld. The frames of this bottom section are intermittently welded to longitudinal bulkhead on one end and to the intercostal girder at the other.

After deck section has been hoisted in position and landed on top corner angle of side section and bar of longitudinal bulkhead, the deck plating is tack welded to toe of top corner angle from the inside, and afterwards the edge of deck plate is fully welded to top corner angle by a continuous fillet weld on the outside. The other end of this deck section is first tack welded to edge of bar of longitudinal bulkhead from the inside. The outside full continuous weld is applied after the next adjacent deck section has been tack welded to the other side of bar of longitudinal bulkhead. Ends of frames of end deck section are intermittently welded to side plating and longitudinal bulkhead respectively.

All other sections of the barge are progressively welded together in a manner as described above.

The H columns, located as shown in way of intercostal girders, are welded to bars of frames top and bottom, by a continuous weld, 5″ long, on both sides of column.

Transverse joints of shell plating located as shown, are fitted with a backing strip, 3″ wide, 1/4″ thick. These strips are tack welded to inside of bottom, sides and deck plating, 2″ weld, spaced about 18″. The gap between plate edges is the same width as that of the corresponding shell plating. The strength weld, applied from the outside, is similar to that of the longitudinal seams of the shell plating, consisting of two fillet welds and one covering weld. After each fillet weld has been completed and before covering weld is applied, it will be necessary to thoroughly caulk each weld, to reduce shrinkage stresses to a minimum. This is very important, having in view the proximity of these transverse as well as longitudinal welded seams and their relations towards each other with reference to shrinkage stresses. In extreme cases, it may also be desirable to locally heat the plates, about 2 feet back of transverse joints, with a view to distributing localized stresses in plate welds after welding is completed. For the same reason, it is also recommended that transverse joints of plates are welded staggered and left to cool thoroughly, before another seam is welded in the vicinity of the previous weld.

Corner angles at headlogs, both top and bottom, after being fitted in position are secured by tack welds, 1″ weld spaced about 3 feet, after which the two flanges are welded by a continuous fillet weld. The two short keel plates at the bottom of each barge end are fitted and secured by tack welds, 1″ weld spaced about 3 feet apart, after which both sides of plates are welded to bottom plates by a continuous fillet weld.

The fender plates are next located at each side of barge by tack welds 1″ wide about 4 feet apart, after which top and bottom edges are welded to barge sides by a continuous fillet weld. Joints in fender plates are made similar to method prescribed for joints of longitudinal shell plates.

In all cases, the size of fillet weld is determined by the thickness of the parts to be joined.

In case buckles should develop in light plates in unsupported areas between stiffeners, due to reaction of residual welding stresses, it is

recommended that a light single bead of welding be applied, either vertically or horizontally, located in way of maximum bulge. This weld will produce shrinkage stresses while cooling, and offset those created by previous welding of bulkhead stiffeners, etc., and will thereby have a tendency to flatten the unsupported portion to its original position. In some cases it will be helpful to apply moderate pressure after the correcting bead has been applied.

Where staggered intermittent welds are specified, it will be of advantage to the welder to use a metal template of about $\frac{1}{16}''$ thickness, on which the position of welds has been indicated by notches.

All deck fittings are welded to the deck by continuous fillet welds.

As work progresses, welds are hammer-tested, but only after welds and adjacent plates are thoroughly cooled.

All watertight seams are tested by filling the compartments with water or by the application of a water stream with a nozzle pressure of not less than 60 lbs. per square inch.

In case any leaks or localized cracks develop in the welding metal, it is removed by chipping, and the section rewelded.

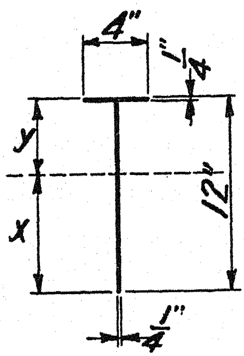
Linear Feet of Welds

Location	Type	Linear feet
Long. joints in bottom, sides & deck	single fillet	4,500
Long. joints in bottom, sides & deck	2 fillet & 1 covering	5,800
Transv. joints in bottom, sides & deck	2 fillet & 1 covering	1,200
Headlog angles	single fillet	200
Headlog bracket	intermittent	50
Transverse bulkheads	2 fillet & 1 covering	600
Transverse bulkheads	single fillet	400
Transverse bulkheads	intermittent	400
Long. bulkheads	2 fillet & 1 covering	720
Long. bulkheads	single fillet	450
Long. bulkheads	intermittent	300
Intercostal girders	intermittent	80
Transverse frames	intermittent	1,575
Frames at ends	intermittent	540
Brackets at ends	intermittent	80
Deck fittings	single fillet	120
Tacks and misc. welds	intermittent	185
Total		17,200

Stress and Loading Calculations

Transverse Frames.—Spacing of frames has been chosen as 2′—0″ from center to center. Total depth of frame to be 12″ with a 4″ cross bar, all of $\frac{1}{4}''$ thickness.

Area of section	=	3.94 sq. inches.
Weight per foot	=	13.40 lbs.
Y	=	4.6 inches.
X	=	7.4 inches.
Moment of inertia I	=	61.0 $inches^4$.
Section Modulus S_x	=	8.25 $inches^3$.



Deck Beams.—

Unsupported length	=	10′-0″
Allowable fibre stress	=	12,000 lbs. per sq. inch.

Considering beam fixed at both ends, then allowable uniform load will be as follows:

$$\text{Bending moment: } \frac{W \times L}{12} = \text{Fibre stress x Section Modulus.}$$

$$\text{Allowable uniform load} = \frac{12{,}000 \times 8.25 \times 12}{120} = 9{,}900 \text{ lbs.}$$

Allowable load per sq. foot of deck area:

$$\frac{9{,}900}{2 \times 8} = 619 \text{ lbs.}$$

Longitudinal Strength Members.—Sketch, Fig. 3 shows net cross-section of barge, from which the following data is derived:

Net area of cross section = 632.0 sq. inches.
(not including reinforcing members of joints and fenders).
Moment of inertia I = 1,873,370 $inches^4$.

As the areas of deck and bottom sections are practically the same, the horizontal neutral axis of the entire cross section is assumed to be symmetrically disposed.

Section Modulus S = 29,271 $inches^3$.

For the purpose of demonstrating longitudinal strength of barge, it is assumed that the barge carries a uniformly distributed deck load of 1,000 tons, and that under these conditions the barge rests on rocks, due to a falling tide or being swept shorewards by heavy sea and wind, in such a manner that the body of the barge is suspended and the ends rest firmly on rocks.

Under these conditions, the body of the barge is subject to the following stresses:

$$\text{Bending Moment: } \frac{W \times L}{8} = \frac{1{,}000 \times 2240 \times 120 \times 12}{8}$$

$$= 403{,}000{,}000 \text{ inch lbs.}$$

This bending moment causes compression stresses along the deck and tension stresses along the bottom of the barge, as follows:

$$\text{Stress} = \frac{403{,}000{,}000}{29{,}271} = 13{,}770 \text{ lbs. per sq. inch.}$$

It is to be noted that even under these most severe conditions, the longitudinal members still have a factor of safety of 4.

Loading conditions.—All loading conditions are based on long tons of 2,240 lbs.

When the barge is uniformly loaded, the capacity in long tons, or draft in feet, is calculated from the following formula:

$$\frac{L \times B \times D \times c}{35} = \text{Capacity in tons.}$$

L = Length in feet.
B = Beam in feet.
D = Draft in feet.
c = Coefficient of displacement.
35 = Number of cubic feet of salt water per ton.
36 = Number of cubic feet of fresh water per ton.

Draft light will be 1.51 feet or 18.15″ in salt water and 1.555 feet or 18.70″ in fresh water.

The following table gives displacement and cargo capacity for salt and fresh water conditions.

Draft in feet	Displacement cubic feet	Salt Water Tons Displ.	Salt Water Cargo Cap. D W Tons	Fresh Water Tons Displ.	Fresh Water Cargo Cap. D W Tons
9′	50,680	1,450	1,225	1,410	1,185
8′	44,680	1,275	1,050	1,240	1,015
7′	38,755	1,105	880	1,075	850
6′	32,926.6	944	719	918	693
5′	27,195.0	778	553	756	531
4′	21,560.0	615	390	598	373
3′	16,021.6	457	232	445	220
2′	10,580.0	304	79	296	71
1′	5,235.0				

Assuming barge is uniformly loaded with a deck cargo of 1,000 tons and that one end compartment is punctured, causing this compartment to be flooded.

Before barge is punctured it is on an even keel and draws 8′-0″ of water; if one end compartment is flooded, then draft at punctured end will be 9′-7½″ and draft at opposite end 6′-4½″. As depth of side is 10′-3″, the damaged end still has a freeboard of 7½″.

In case one side compartment is damaged and flooded under the same loading conditions, we find that the barge will heel over at an

angle of about 4¼° with corresponding freeboard on flooded side of 8½″ and on opposite side of 3′-11″.

MATERIALS

Plating.—Side plating to be 25.5 lbs., deck and bottom plating 15.3 lbs., rake and end plating 25.5 lbs. All bulkheads to be 12.75 lbs. plating. All butts to be fitted with straps, about 3″ wide and ¼″ thick.

Framing.—Bottom, side and deck framing to be of special construction, consisting of 10.2 lb. plates, provided with a 4″ flange. All frames are spaced 24″.

Deck girder to be topped with 4″ bar to re-enforce deck seam, bottom girder to rest on a flat keel plate 9″ x 15.3 lb.

Longitudinal stiffeners to consist of 4″ x 4″ x 5⁄16″ angles, bottom corners to be 5″ x 5″ x ½″ angles, deck corners to be 4″ x 4″ x ⅜″ angles.

Framing for ends to consist of 4″ x 4″ x 5⁄16″ angles, to be fitted with brackets at corners.

Headlog plate to be re-enforced with special brackets. Vertical and horizontal braces to consist of 3″ x 3″ x ¼″ angles. Side framing at ends to be 12″ deep, 4″ flange, 10.2 lb. plates, spaced 24″.

Columns to be 5″ x 18.9 lbs. H beams spaced and welded to deck and bottom frames.

Bulkheads.—There will be two longitudinal watertight bulkheads of 12.75 lbs. plating extending from end bulkhead to end bulkhead.

5 transverse bulkheads of 12.75 lbs. plating divide the barge into 11 watertight compartments.

All bulkheads to be stiffened by horizontal and vertical angle bars, 4″ x 4″ x 5⁄16″.

The longitudinal bulkhead will rest on a keel plate 9″ wide by ½″ thick. The top of the bulkhead will have a bar 4″ x 5⁄16″ fitted and welded to re-enforce weld of deck plating.

Comparison of Weights and Cost.—In comparing this welded design with that of a riveted barge of the same size, plate thickness and strength, the difference in weight may be analysed as follows:

Riveted joints require an overlap at plate edges of about 2″ and by using the same width and length of plates as called for in the welded design, each individual plate will be 4″ wider and 4″ longer.

Using the deck plating as an example it follows that

weight of welded deck plating and butt straps	=	91,000 lbs.
weight of riveted deck plating	=	103,200 lbs.
Difference		11,800 lbs. or 12½%

Naturally the same difference will apply to sides and bottom plating.

Regarding frames:

Weight of welded frame per foot	=	13.40 lbs.
Riveted type: channel of same moment of inertia : 10″ x 15.3 lbs.	=	15.30 lbs.
Difference		1.90 lbs. or 14%

A similar difference will apply to bulkheads and bulkhead stiffeners or an average of 13%.

Total average difference of riveted barge as compared with welded barge will be 13.2% in favor of welded design.

Weight of welded barge complete, not painted = 500,000 lbs.
Weight of riveted barge complete, not painted = 565,000 lbs.

The riveted type of construction requires more labor, as all plates and shapes have to be marked off, punched, assembled by bolts and holes reamed before rivets are driven. This also requires greater handling charges; therefore the cost of labor is much higher.

The riveted construction requires a large amount of equipment, such as punches, shears, drill presses, riveting machines, caulking tools, which also will result in higher charges for overhead.

The total difference may be summarized as follows:
(values are given in cents per pound)

	Riveted Type	Welded Type
Cost of material	3.035	3.035
Labor	1.027	.790
Overhead	1.129	.800
Manufacturing cost	5.191	4.625

Taking into consideration that the riveted barge is 13.2% heavier than the welded design, the respective values representing manufacturing costs are:

Riveted barge 565,000 lbs. at 5.191	=	$ 29,320.
Welded barge 500,000 lbs. at 4.625	=	23,125.

Thus the riveted barge costs $6,195.00 or 26.78% more than does the welded barge.

In addition the welded barge has a carrying capacity of 13.2% in excess of that of the riveted barge, or a barge this size of the riveted type has a nominal capacity of 868 tons as compared with the welded type of 1,000 tons.

Chapter III—Redesign of Midship Section of Great Lakes Freighter for Arc Welded Construction

By Stanley A. Midnight,
Structural designer, hull department, American Ship Building Co., Cleveland, Ohio.

This paper covers the redesign of the midship section of a modern Great Lakes bulk freighter, (See Fig. 1), to employ the use of arc welding, (See Fig. 2), in place of the present riveted construction, (See Fig. 3). Previously, these bulk freighters were built of all-riveted construction. However, four freighters just completed, two each at the yards of the American Shipbuilding Company and The Great Lakes Engineering Works have now employed the use of arc welding to a very limited extent.

Generally speaking the midship section covers the design of approximately 90% of the total steel making up the hull structure excluding the deck houses. However, the writer believes that the same proportionate savings in cost and weight could be made on the remaining 10% of the hull structure, but lack of time in preparing such a large project in spare time has limited the scope of this paper to the midship section design.

In designing the arc welded vessel the writer has adhered to the rules of the American Bureau of Shipping as well as to the general fundamentals of strength calculation of steel structures. The text "Procedure Handbook of Arc Welding Design and Practice" by the Lincoln Electric Company was used for reference with regard to the design and practice of arc welding and the method of computing costs of the various types of joints.

Longitudinal Strength.—In designing the present vessel, the author has, therefore, followed accepted practice. The moment of inertia of the riveted vessel was reduced 12.5% which is a reduction for rivet holes and is the figure generally assumed. This gives the comparative section modulus of 18,400 inches^2 feet for the riveted vessel as compared to 18,802 inches^2 feet for the arc welded vessel.

(a) Longitudinal framing effect on calculated strength.—The tank top longitudinals and bottom longitudinals were calculated as forming part of the section modulus of the vessel. While this would probably be correct for the comparison of two longitudinally framed vessels, it does not appear to give a true picture in the case of a longitudinally framed vessel compared to one transversely framed.

For example the tank top longitudinals act as a beam in supporting the cargo load between supports and as such they are stressed up to the working stress of the steel. In addition to this they must also assume their share of the longitudinal stress in the vessel. This combination of bending and direct tension or compression, stresses these members above the working value of the steel, giving an unbalanced design.

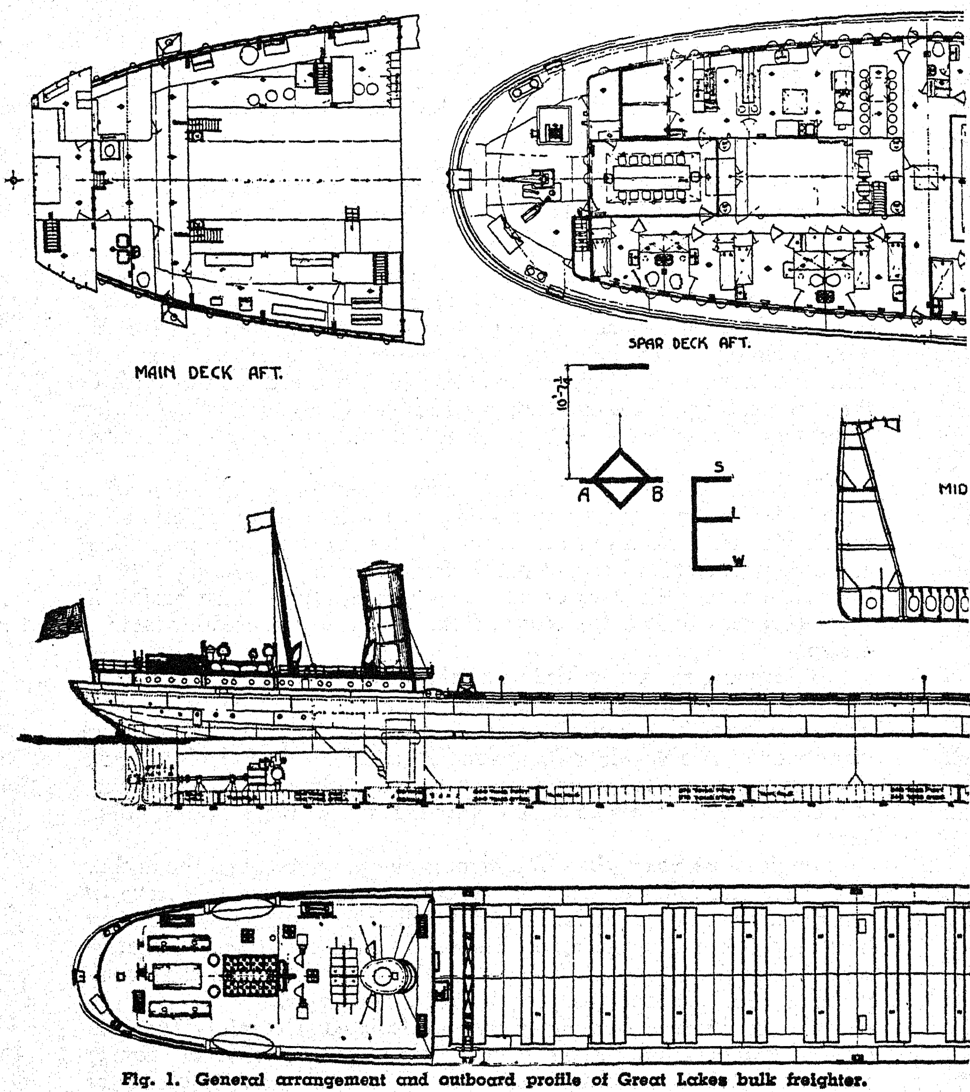
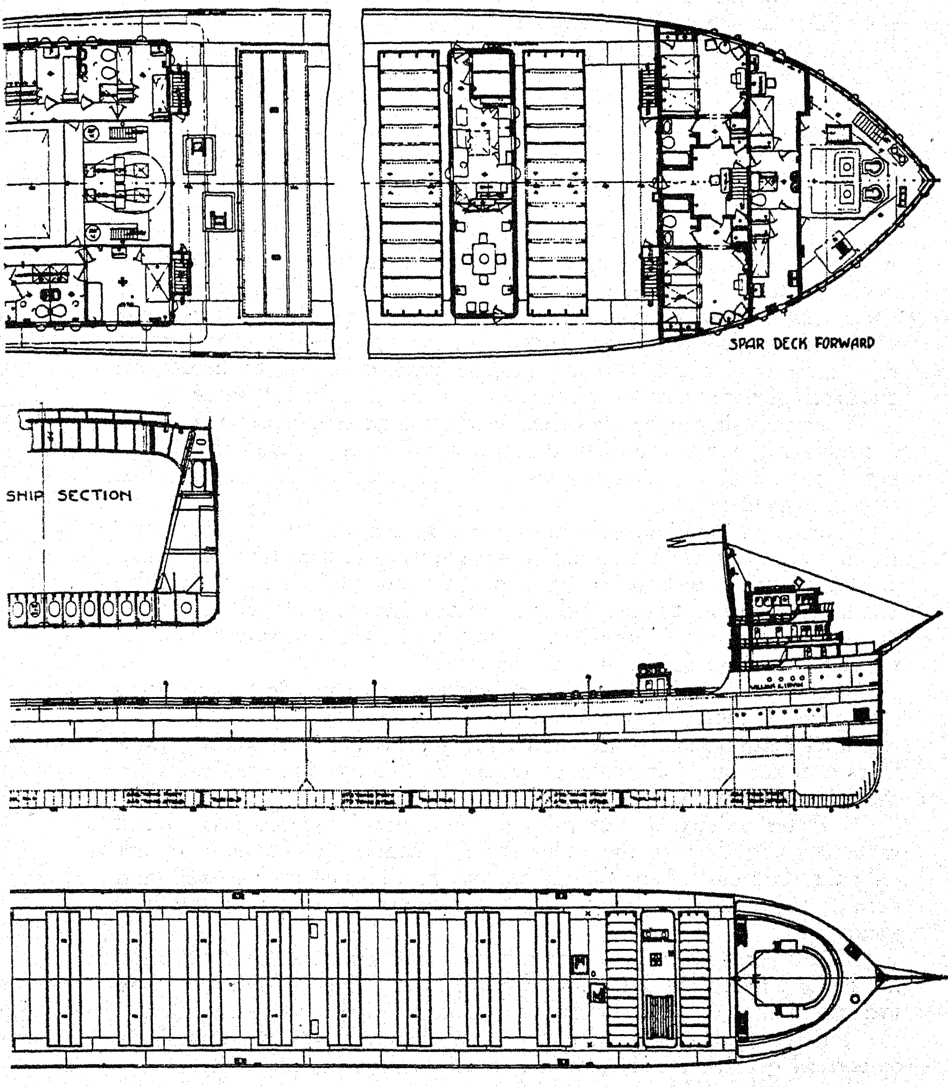


Fig. 1. General arrangement and outboard profile of Great Lakes bulk freighter.

(b) Effect of riveted joints on longitudinal strength.—Rivet holes in some strength members necessitate a reduction in the strength calculation varying from 65% to 80% depending upon the type of joint. In addition, considerable difficulty has been encountered in the past with certain of the riveted joints. For example, the spar deck stringer plates being about 1¼" thick, had double butt strap joints. Due to the great thickness of the plates and the 1¼" rivets used, the pneumatic riveting was unable to draw the plates tight together and consequently severe slippage often



occurred. The condition was bettered with the advent in recent years of a scarphed buttlap joint. In theory this type is not as good as the strapped joint, but the scarphing permitted the use of a much shorter rivet and allowed a tighter drawing up of the plates, which in practice produced a much stronger joint. But this type of joint as in plain lap joints puts tension in the end rivets and the direct stress causes bending in the plate, which reduces the strength of the plate.

Other riveted conditions which do not give 100% strength are, for

example, the tank top longitudinals which are bracketed to a water tight floor and the side keelsons which are clipped to the floors. The stress in the tank top longitudinals is, therefore, transmitted through an eccentric joint and when in tension through the rivet heads. Likewise, the stress in the side keelson is transmitted through the angle clip and when in tension the rivets are in tension, which puts all the stress in the rivet heads. For this reason, the American Bureau of Shipping rules only allow the side keelson to be counted for one half of its value in computing the section modulus.

Similarly the hatch girder has not been included in the section modulus of the riveted vessel for the following two reasons; (1) The girder is clipped in a fore and aft direction; (2) it supports the deck between webs, thus putting a secondary or local stress in the girder. In the case of the arc welded vessel, the welded butt joint gives 100% strength and the design eliminates local stresses as the brackets at each frame support the hatch girder so that the girder has been counted for full value.

Therefore, it can be seen that welding eliminates many joints that are inherently weak and adds to the longitudinal strength of the welded vessel considerably, although these facts do not show up in the usual strength calculations.

Transverse Framing.—For the several reasons mentioned above and the fact that transverse framing allows the inner bottom tank to be conveniently built in sections in the shop, it was adopted for the arc welded vessel. In addition it appears that a great resistance is offered to racking or twisting which is so prevalent in the lake ships and is probably due to the high length to depth ratio of about 18½ to 1.

Therefore, it is felt that the arc welded vessel in addition to being stronger longitudinally, is much stronger transversely.

Shell Plate Seams.—The welded lap joint seams have many advantages over the butt joint from a construction or erection standpoint for the following reasons:

1. Plates ordered to size from the mill may be placed and welded without going through the shops for fabrication. This eliminates not only the shop cost of the fabrication but handling charges as well, and permits the placing of longer strakes, thereby eliminating many butt joints.

2. Lap joints allow for erection adjustments since the lap width need not be held to a fixed dimension, whereas, butt joints require very close fitting and must be welded together in fixed relationship to each other.

3. Fillet welds being easier to make than butt welds in an overhead or vertical position are cheaper and should be of a higher quality.

4. Since the primary purpose of the seams is to take up the horizontal sheer between the plates, the lap joint is just as desirable as the butt joint.

5. The seam is not waste material in that it adds to the longitudinal strength of the ship.

For the foregoing reasons, lap joints were adopted for all shell plate seams in the arc welded vessel.

Shell Plate Butts.—As pointed out above, lap joints are more desirable and cheaper for seams, since the strength of the two joints are equal for this particular case. However, in the case of longitudinal or, end

joints, the author does not believe that a joggled lap is nearly as desirable as a butt joint as far as strength is concerned. It is a well known fact that a riveted or welded lap joint in tension or compression produces a considerable bending stress adjacent to the lap which is very undesirable and reduces the strength of the plate. For these reasons, the end joints in the shell plating were designed as butt joints.

Shop Assemblies.—Since the vessel has such a large portion of its length made up of multiple units it lends itself readily to the practice of building the units in the shop and assembling them on the ways. This general method was employed on the riveted vessel, although to a limited extent. For example, the frames in the side tanks both upper and lower were assembled in the shop.

The general scheme then, on the welded construction is to be similar except that it is proposed to assemble several of the frames into a unit and place this unit on the vessel. This procedure will lower the erection costs as it will allow much of the welding to be done in a flat position in the shop and it also will permit the use of special jigs for accurate assembly and a corresponding reduction in cost.

The inner bottom tanks are to be assembled complete in units 12 feet long. This includes the floor plates, tank top plates, side keelson plates, diagonal angle braces, flat bars on floor plates, channel tank top stiffeners and brackets. This arrangement will permit downhand welding throughout the unit. The proposed method of assembling would be as follows:

1. Mark and burn out holes and shell edge in plate floors.
   (a) Place and weld diagonals thereto. (Diagonal angles will be ordered to length from the mill.)
   (b) Place and weld flat bars making plate floors complete.
2. The plate floors and side keelson shall then be welded together forming a honeycomb section. This will allow for any distortion that might result from welding the keelson to the floor.
3. The tank top intermediate stiffeners shall next be welded to the tank top plate, after which the plates shall be butt welded to form a 12-foot unit. (This permits an ideal setup for automatic welding).
4. The honeycomb section shall then be placed on the tank top plate and welded thereto.

The weight of this unit assembly will be about six and one half tons which can be conveniently handled by the cranes.

The lower side tanks including the outer floors, lower side frames, main deck brackets, hopper side stiffeners, stringer ties, lower web frames, hopper side stringer, main deck stringer plates and the bilge strake plate shall be assembled in the shop in one unit 24 feet in length. The detail procedure will be similar to the inner bottom tank unit. The unit weight will be approximately 11 tons and may be handled by the cranes.

The upper side tank consisting of the side frames, upper web frames, hopper side stiffeners and brackets, hopper side "E" strake, hatch girder brackets, arch brackets and hatch girder will be assembled in the shop in a 24-foot unit. The assembly will eliminate a great deal of the work which was costly due to the erection procedure necessary on the riveted vessel, and the unit weight will be about 6½ tons.

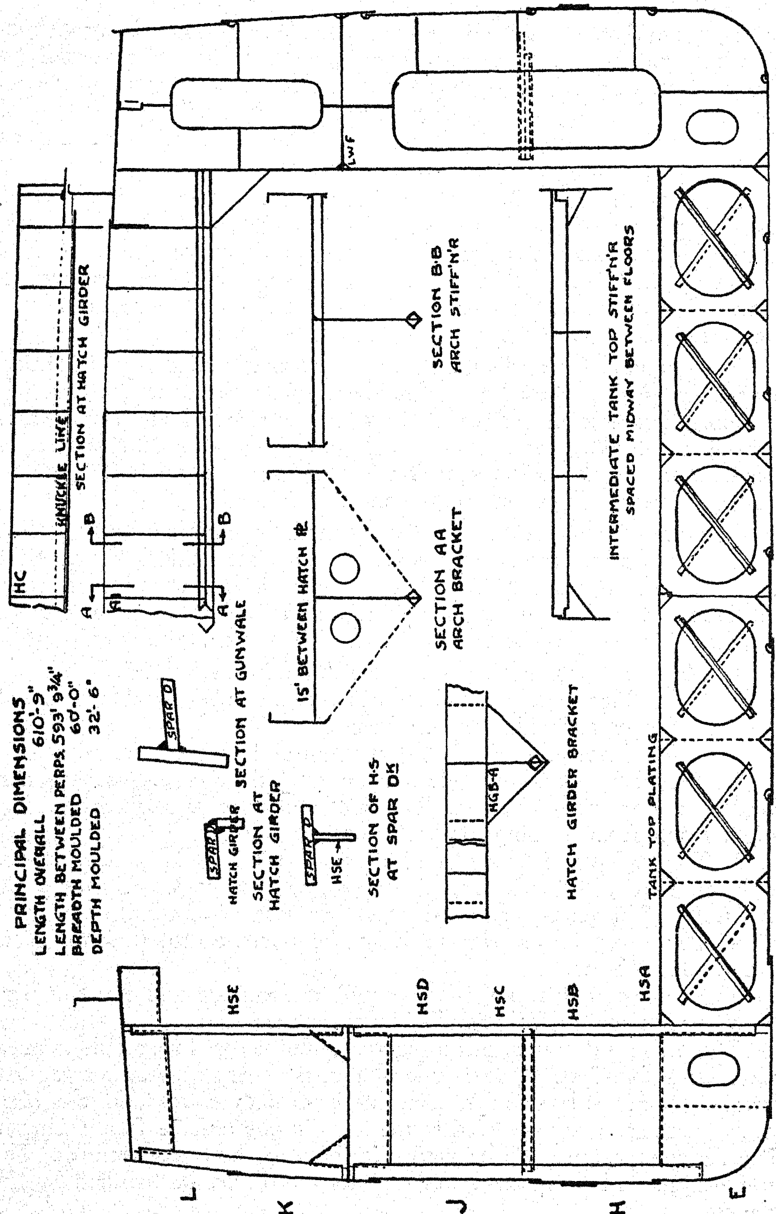


Fig. 2. Midship section of Great Lakes bulk freighter designed for arc welding. Compare with Fig. 3. See also page 337b.

The arch will be assembled complete including the 'tween deck hatch plates and the side hatch coaming plate and will have a unit weight of about 6½ tons.

General Plan of Construction On Ways.—1. As in the riveted

PRINCIPAL DIMENSIONS

Length Overall	610'-9"
Length Between Perps.	593'-9¾"
Breadth Moulded	60'-0"
Depth Moulded	32'-6"

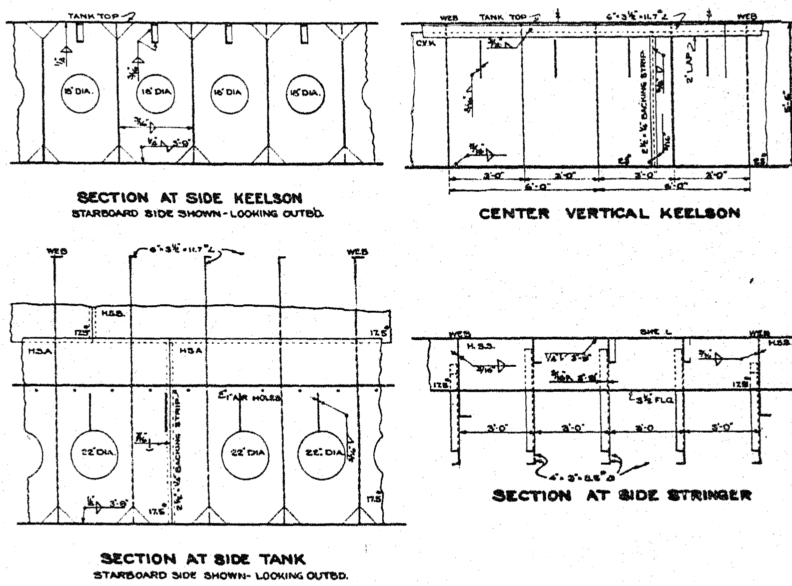


Fig. 2. Additional details to page 337a which see.

construction the center vertical keelson shall be erected first. The shell plates will be 48 feet in length, with the exception of the bilge strake which will be 24 feet. The "A" strake end butt joints should be welded prior to the welding of the keel plate onto the "A" strake. The center vertical keelson top angle should be welded to the center vertical keelson plate with an automatic machine before welding the center vertical plate onto the bottom strake. The erection should start amidship and work toward the ends.

2. The shell bottom strakes, "B" "C" and "D" shall be placed amidship and worked toward the ends and follow the same procedure of welding the end butt joints prior to welding the seams. The general plan of aligning the seams as a measured distance from the center vertical keelson will keep the seams straight. It is planned to place the inboard fillets with an automatic machine and the outboard manually.

3. The inner bottom tank unit assembled in the shop shall then be placed and all butt joints of longitudinal members welded prior to welding the transverse members.

4. The hopper side "A" strake shall next be placed and the end butts welded first and then the remaining welding placed.

5. The lower side tank units of 24-foot lengths, shall be placed next and the end butts of the longitudinal members welded first. The miscellaneous remaining welding can then be done. A portable cross arm

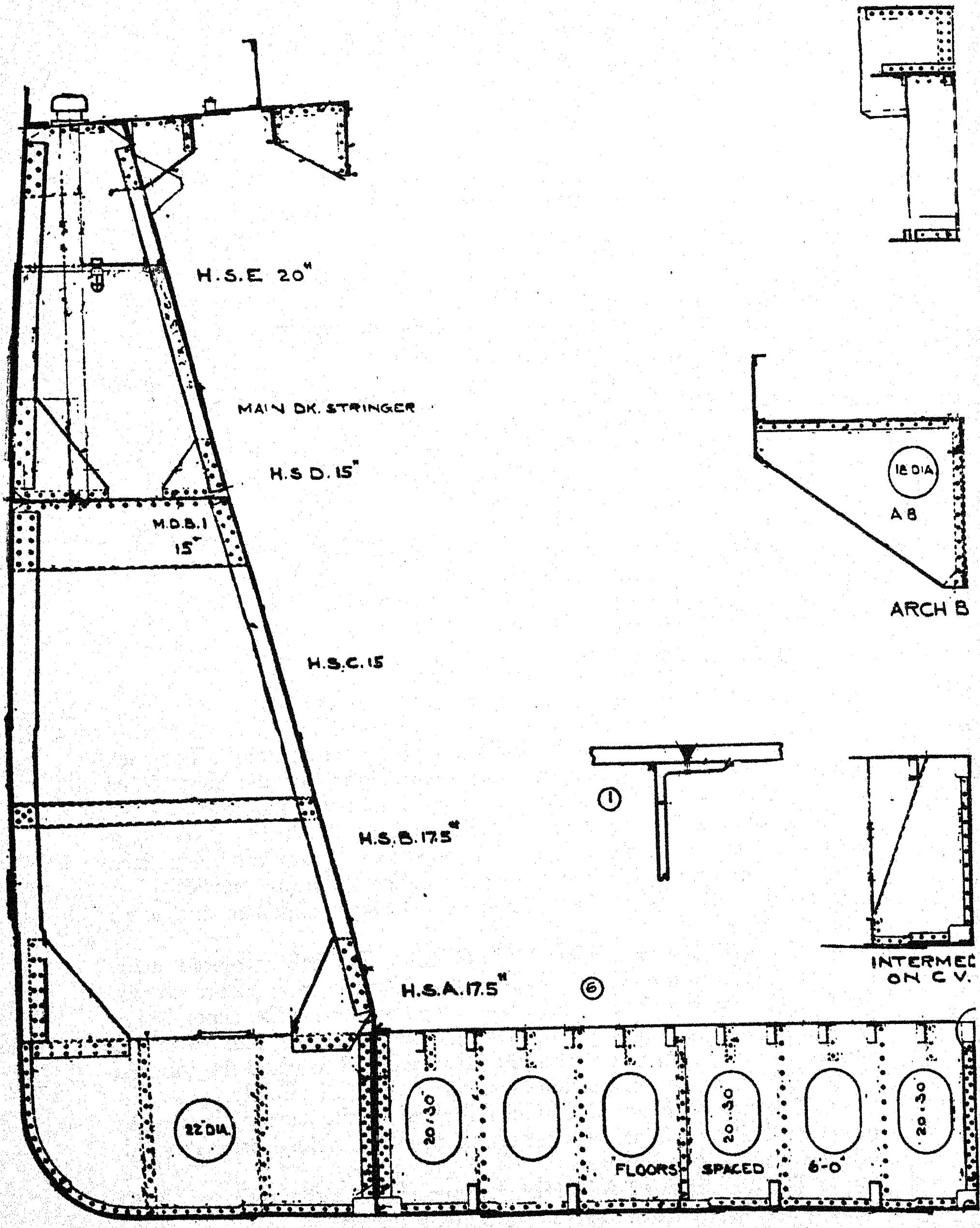
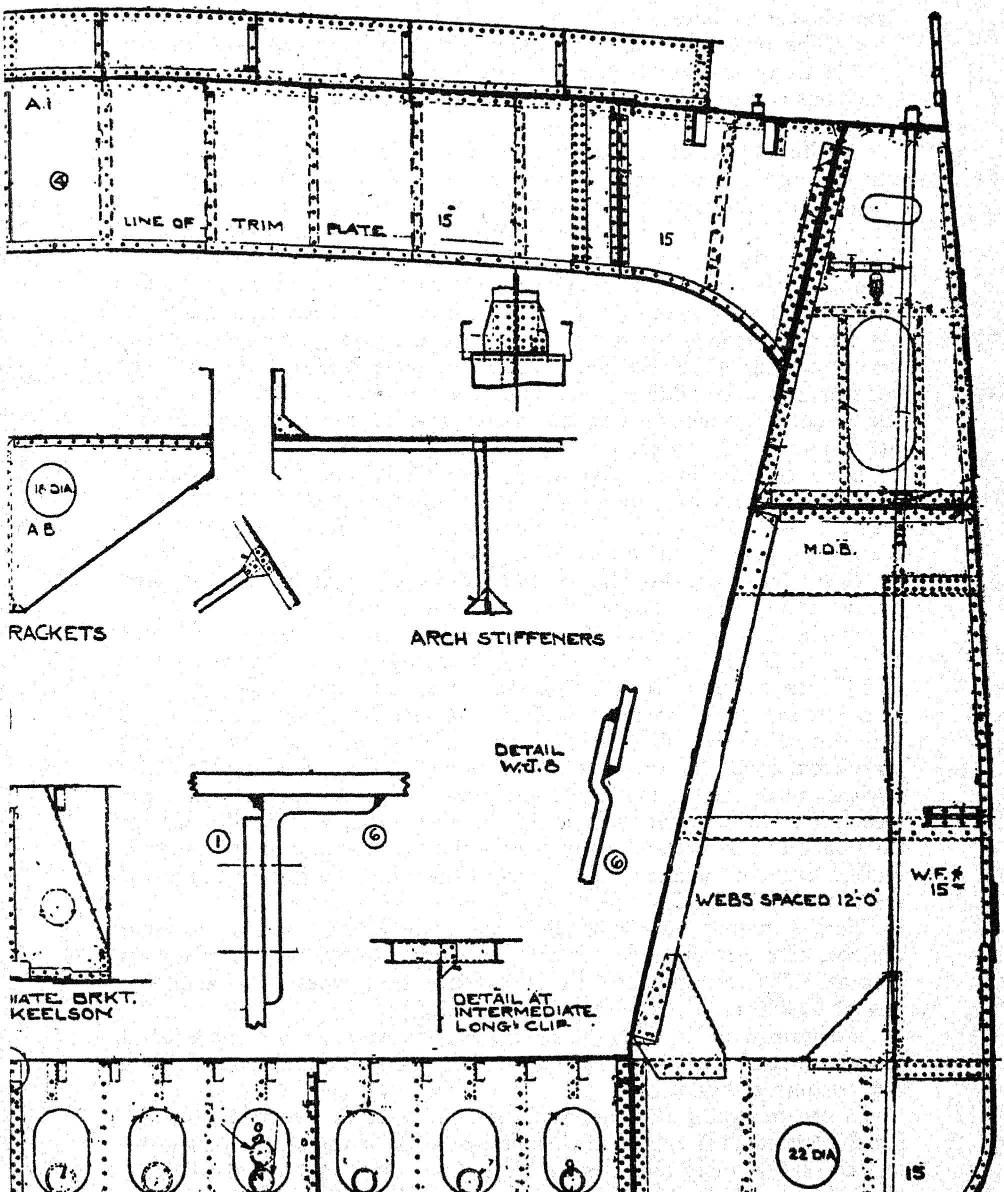


Fig. 3. Conventional riveted design of midship section of Great Lakes bulk freighter. Compare with Fig. 2.


A.1
4
LINE OF TRIM PLATE
15
15
18 DIA
A B
RACKETS
ARCH STIFFENERS
M.D.B.
DETAIL W.T.B
1
6
6
WEBS SPACED 12'-0"
W.F. & 15
IATE BRKT. KEELSON
DETAIL AT INTERMEDIATE LONG' CLIP
22 DIA
15

should be built to keep the hopper sides vertical and correctly spaced from the center line.

6. The upper side tank assembly can then be placed and the end butt joints of longitudinal members welded prior to the other welding. The construction should be simultaneous with the other side so that correct alignment will be kept.

7. The hopper sides shall next be placed, care being taken to weld the longitudinal end butts prior to the permanent seam welding.

8. After the hopper sides, the spar deck longitudinal channels and the spar deck stringer plate can be placed. The stringer plate will be in 24-foot lengths and the longitudinal channel in 72-foot lengths.

9. The arch assembly can then be placed and the writer believes this to be the simplest arch to construct and erect of any previous design on the lakes. It merely has to be set onto the deck stringer plates and will be supported by the 'tween deck hatch plate overlapping onto the stringer plate. In addition, the arch plate can be left a little long until the exact span is measured and then the arch plate can be burned to exact fit. The welding can then be completed.

10. After the lower side tank has been placed, the shell plates can be placed in order while steps 6 to 10 are being erected. Care should be taken to weld all longitudinal butts before the seams. The last shell plate to be placed will be the "K" strake.

Cost Comparison.—The method of breaking down costs of hull construction which follows will be on a per-pound basis.

Steel.—The weight of a 24-foot section of the riveted hull is 164.36 short tons. Allowing 8% for scrap and adding 10 tons of rivets, a total of 187.5 short tons of steel is required for the construction of the riveted vessel section. 137.79 tons of steel are required for the arc welded vessel. The design of the arc welded vessel makes possible the reduction of scrap from about 8% to about 2%. Figs. 4 and 5 indicate how the plates burned out of the inner floor plates, lower web frame plates and upper web frame plates provide all the side keelson plates, and the 5″ flat bars, the upper side frames and many other brackets. The cost of the electrode will be included under welding costs so that the total steel required for the arc welded vessel is 140.55 tons.

This represents a saving of 47 tons or 25.0% of the steel cost. Since the cost of the steel in the riveted vessel represented 52% of the total cost, a 25.0% reduction for the arc welded vessel, gives a corresponding cost of 39.0% for the steel in the arc welded vessel.

Designing and Drafting.—Preparation of arc welded vessel plans and specifications is a major job when welding procedure and practice have not become standardized.

In others words, more designing is imperative for reduced costs and for this reason it is estimated that design work of the arc welded vessel will be slightly more than for the riveted one due to the standardization of the riveted hull. On the other hand welding eliminates many connection members and makes a simple design when properly done and this fact would tend to lower the drafting costs.

Considered as a whole, the design and drafting cost of the arc welded vessel will be assumed to be the same as for the riveted vessel.

Mold Loft.—The elimination of all connecting members reduces the

work of the mold loft about 20%. In addition, it is planned to order much of the steel direct from the mill to size which will eliminate many of the separate molds for individual pieces. As a substitute, overall molds of units will be needed, but these will be few and a gross savings will, therefore, be made. Furthermore, no rivet holes are necessary, saving considerable time of the loftsmen. In view of all this, it is estimated that at least a net savings of 25% can be effected in the mold loft cost.

Handling.—This item covers the necessary handling of the steel from the freight car through the fabricating shop to the vessel. In the case of the riveted vessel, every plate and shape went through the shop. In the arc welded vessel, figures indicate that about 60% of the steel will be placed on the vessel without going through the fabricating shop. Of the remaining 40%, which will go through the welding erection shop, about 25% of it will also go through the fabricating shops. The steel going through the fabricating shop for arc welded construction will not have as much handling as that for the riveted vessel since some of the operations

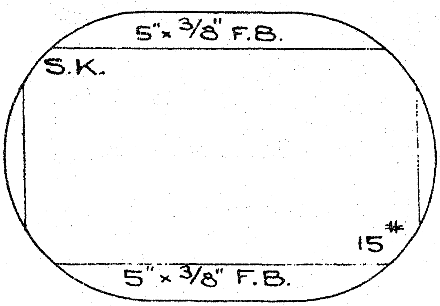


PLATE CUT FROM INNER FLOOR PLATE PROVIDES ALL SIDE KEELSONS & MISC. FLAT BARS.

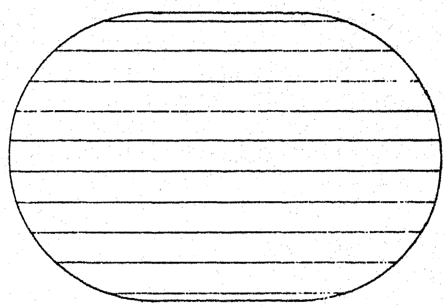


PLATE CUT FROM INNER FLOOR PLATE PROVIDES MISC. 5" x 3/8" FLAT BARS.

Fig. 4. Design of arc welded vessel permits reduction in scrap from approximately 8% to approximately 2%.

such as punching will not be necessary. In view of the above, it is estimated that the handling charges can be reduced at least 50%.

Fabrication.—Fabrication costs as applied to the riveted vessel included the work of preparing the steel for assembling and, to some extent, the assembling of units for erection on the vessel.

In the case of the arc welded vessel, fabrication will include the costs of preparing the steel for assembling and the pre-fabrication of units for erection on the vessel.

This makes possible the following savings:

(1) There is 16.2% less steel in the arc welded vessel.

(2) 60% of the steel requires practically no fabrication as it consists chiefly of the shell plating and hopper side plating and the only work will be to chip or burn the ends for welding, which can be done on the vessel.

(3) There are no rivet holes to punch.

(4) Many of the members can be ordered to size.

(5) There is no joggling of shapes required in pre-heating or otherwise.

(6) The use of jigs or forms for assembly of units will eliminate considerable assembly costs.
(7) The use of welding turn tables and rotating machines in the shop will keep the pre-fabricating costs at a minimum, as it will permit downhand welding throughout the units, speed up the operations, and eliminate much of the crane work.

Since it is planned to do considerable more pre-fabricating with the arc welded vessel it will offset some of these savings. Considered as a whole, however, the figures indicate that the fabrication costs will be reduced to 50% of the riveted vessel costs.

Erecting.—This includes the cost of erecting the steel on the vessel and all work incidental thereto, such as, reaming, caulking, etc. The latter are entirely eliminated in the case of the arc welded vessel and will save considerable expense.

In the case of the arc welded vessel, the entire vessel with the exception of the shell plates, hopper side plates and spar deck longitudinal channels will be built in the shop in units. This fact should lower the erection costs inasmuch as it cuts the erection work on the vessel to a fraction of the work of the riveted vessel. In addition it is felt that the design permits a still further saving due to its simplicity.

Considered as a whole, the estimated figure indicates cost savings of at least 30% over the riveted vessel.

Bolting Up.—The cost of bolting up will be assumed to be the same as clamping, etc., for welding. From the best information available the cost of bolting up is more than the cost of clamping, pulling up, etc., in welding, especially when it is considered that a large part of the assembling is to be done in the shop; but to be conservative the author will assume the costs to be equal. In the riveted vessel, bolting up costs amounted to about 3% of the total.

Welding and Riveting.—Figures indicate that 14% of the cost of the riveted hull was for riveting and small amount of welding used. The cost of the welding on the arc welded vessel, \$1882.90, is estimated from the formulae given in "Procedure Handbook of Arc Welding Design and Practice."

The costs of the riveted construction, are actual shop costs and do not include overhead except for immediate supervisory charges. Therefore, for the comparative arc welding costs, a 25% allowance has been made for the arc welding supervision. In addition to this, a 10% allowance has been made for the miscellaneous small amounts of welding not readily accounted for.

The estimated welding cost of \$1,882.90 is 86% of the riveting cost in the riveted vessel, which gives a comparative cost of 12% for the welding in the arc welded vessel.

Summary of Comparative Costs.—As can be seen from the summary table below, the cost of the arc welded vessel is estimated at 74.1% of the riveted vessel. Additional methods have been outlined in this paper which would still further reduce the cost of the arc welded vessel, but lack of definite cost figures which must be secured from actual practice, prevented showing these economies. The author refers specifically to the

adoption of automatic welding and the additional savings would be considerable as the design has been prepared for these advantages.

Comparative Cost of Riveted and Arc Welded Vessel

Item	Riveted	Arc Welded
Steel	52.0%	39.0%
Drafting & designing	1.0%	1.0%
Mold Loft	2.0%	1.5%
Handling	2.0%	1.0%
Fabrication	8.0%	4.0%
Erecting	18.0%	12.6%
Bolting Up	3.0%	3.0%
Riveting & Welding	14.0%	12.0%
	100.0%	74.1%

Conclusion.—The arc welded midship section, as shown in the detailed plan, Fig. 2 and as outlined in this paper has the following advantages and savings as compared to the riveted midship section of the most modern of the Great Lakes bulk freighters.

1. A proportionate cost saving of 25.9% through the adoption of the arc welded vessel described in this paper is claimed and the author believes he has substantiated and proven these claims with conservative estimates of cost.

2. The gross savings accruing to industry through the general adoption of the arc welded design are as follows:

(a) A proportionate cost saving of 25.9%, makes a saving of about $200,000 in the construction of the hull structure of one vessel and since about 180 vessels would be

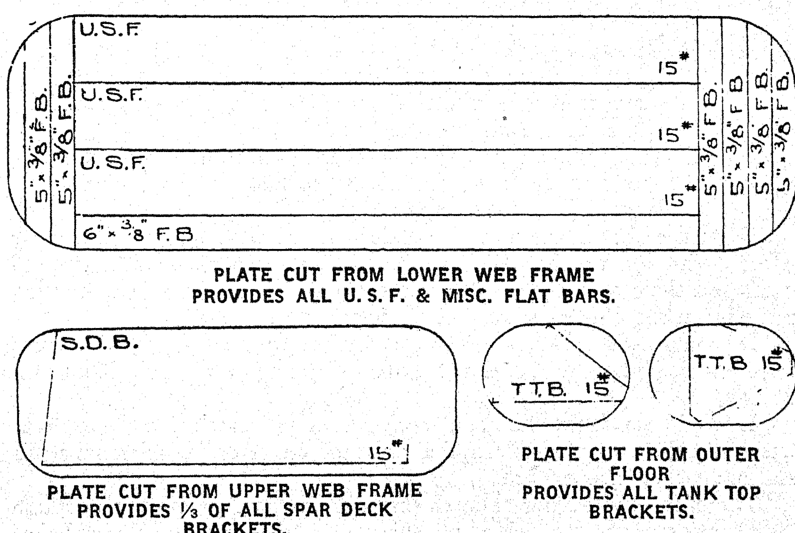


Fig. 5. Saving scrap by arc welded design. Utilization of plates cut from web frames and outer floors.

required to carry peak year iron ore loads, a total savings of \$36,000,000 is effected.

(b) Based on the 1937 bulk cargo movements of iron ore and coal on the Great Lakes and their respective shipping rates, the total transportation charges amounted in the year to about \$78,000,000. An increased pay load of 5% due to the decreased hull weight, effects a savings of approximately \$3,900,000 a year.

(c) The first cost savings mentioned above would reduce interest on investment, insurance charges and repair expenses about \$40,000 per vessel per year, giving a total yearly savings of about \$7,200,000.

Therefore, the general adoption of the arc welded midship section for a modern Great Lakes bulk freighter effects a first cost savings of \$36,000,000 and thereafter, a yearly savings of \$11,100,000.

3. Increased service life, efficiency and general economy and social advantage provided to mankind by the adoption of the arc welded midship section are as follows:

(a) The arc welded vessel would be stronger than the riveted vessel, thus providing greater safety at sea.

(b) Repair expense should be reduced as it will not be necessary to replace loose rivets, especially after severe storms. It was not uncommon in the past to have one of the bulk freighters limp into port and dry dock, to have as many as 30,000 to 40,000 rivets replaced after a severe storm.

(c) The elimination of lapped or strapped end joints in shell plates of the arc welded vessel will reduce the friction of the vessel traveling through the water, thereby increasing its efficiency and general economy in addition to presenting a much neater appearance.

(d) The substitution of butt joints for lapped joints in the spar deck stringer provides a smooth deck making it a safer deck for walking thus eliminating a safety hazard which should reduce accidents.

(e) The elimination of crevices and seams in connections, obstructs the deterioration by corrosion, which permits longer life and cuts repair bills.

From the above, one may conclude that the advantages and savings effected through the adoption of the arc welded vessel are many and great and these savings would possibly be passed on to many industries, not only in the United States but throughout the world.

It would assist in keeping the competitive front of foreign iron ores from encroaching on the Great Lakes shipping and shipbuilding industries.

It would also assist the great steel industries located along the Great Lakes shorelines in maintaining their competitive front with foreign steels and increasing their exports.

Therefore, the author believes that the cost savings effected through the adoption of the arc welded midship section for a modern Great Lakes bulk freighter would have a far reaching effect and provide lower steel costs for mankind in many parts of the world.

Chapter IV—Saving in Cost and Weight by Welded Construction of a Railroad Car Float

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Acknowledgements.—The writer is indebted to Mr. Hugh S. Knerr, of the cost engineering department of the Newport News Shipbuilding and Dry Dock Company for valuable assistance in the preparation of cost figures; to Mr. John F. Watson and Mr. S. A. Vincent of the same company for assistance in the design; and to the American Bureau of Shipping, who kindly examined the designs and suggested changes whereby they could qualify for the approval of that organization.

The purpose of this paper is to present a design for a railroad car float, both for riveted and welded construction. The riveted and welded hulls have been designed to give equivalent strength, and resultant savings in weight and cost will be examined and evaluated, both for this particular design and for the broad application of these savings throughout the railroad operated fleets.

Description of Service Conditions.—Railroad car floats are used for the transfer of railroad cars across water, in cases where bridges and tunnels are lacking, or to supplement existing bridges and tunnels. They are used in New York, Philadelphia, Baltimore, Hampton Roads, New Orleans, San Francisco, and other harbors.

The ends of the car floats are designed to fit special loading bridges or platforms at the terminals, and although some vessels must be loaded and unloaded from the same end, most of them are double-ended. The floats are transported in some cases, as in New York harbor, by a tug alongside, and in others by a tug ahead, using a towline.

There are many variations in the design of car floats, with respect to type of cars carried, methods of loading, whether flush-decked or with loading platforms for handling freight, or whether open or partially enclosed. Some are for service in sheltered waters, and have no independent arrangements for steering. Others are for open-water service, and have power steering gear and a navigating bridge straddling the hull. It is this latter type which is being considered in this paper. These car floats are used in Hampton Roads, between Cape Charles, Norfolk, and Newport News, most of the run being made through waters which at times are very rough, and as the schedule calls for a twenty-four hour service, strength is an important consideration.

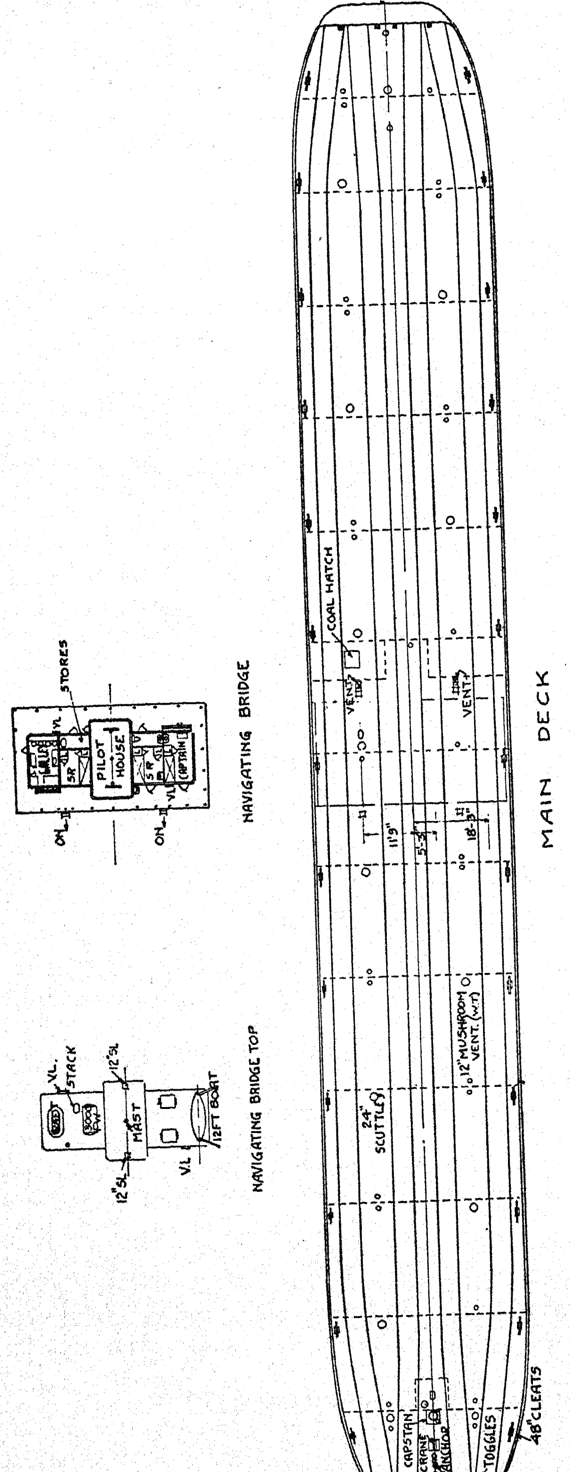

Fig. 1. General arrangement of railroad car float. **See also page 345b.**

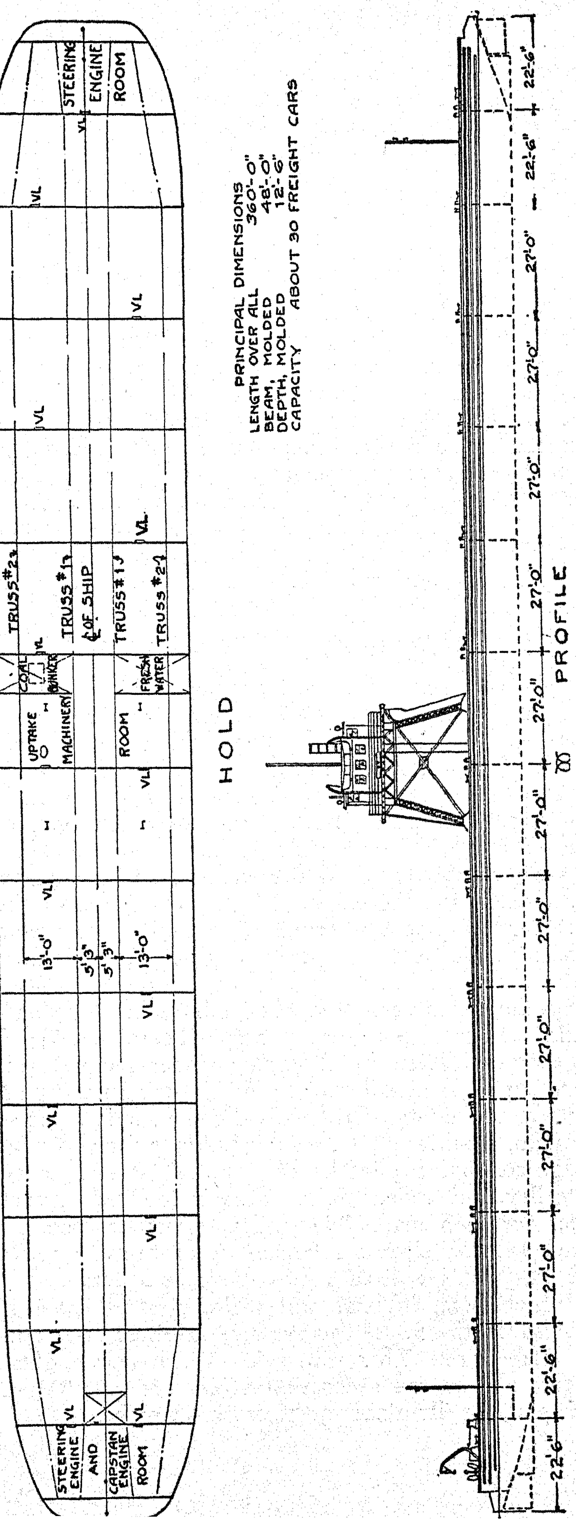

Fig. 1. General arrangement of railroad car float. See also page 345a.

The general arrangement of the car float under consideration, (See Fig. 1), is typical of those used by the Pennsylvania Railroad and the Chesapeake and Ohio Railroad. The principal particulars are as follows:

Length over all	360′–0″
Beam, molded	48′–0″
Depth, molded	12′–6″
Car capacity	30 freight cars

General Description.—This car float is of the flush-deck type, with four tracks. Eight cars may be placed on each inside track and seven on each outside track, making a total of thirty cars. Due to the size and service conditions of this car float, a rudder is fitted at each end, controlled from the bridge which is supported above the main hull. The hull has thirteen main transverse water tight bulkheads, dividing the float into fourteen compartments, excluding the small peak compartments at the ends. There are four full depth longitudinal truss girders, and the deck and shell are longitudinally framed. For a long, shallow vessel of this type, the longitudinal system of framing is more efficient than the transverse type generally used. The truss girders are centered under each pair of rails, and under each rail is a six inch channel, supported every three feet by brackets to the top chord of the truss girder. (See Fig. 2).

The bridge-supporting structure is constructed of truss work, and is supported under the main deck by columns under each leg. The navigating bridge, deck house, and house tops are all constructed of steel, as well as the bulkheads within the deck house.

At one end of the car float is stowed an anchor, with a special crane which places the anchor beyond the end of the vessel, so that it may be raised or lowered by a combined steam windlass and capstan. The capstan engine is located in the steering gear compartment together with a steam steering engine. At the other end of the vessel, only the steering equipment is fitted. The steering engines are controlled by telemotor connected to two steering wheels located in the pilot house.

In the machinery space is a donkey boiler, coal fired, to supply steam for the various auxiliary machinery. There is a 7½ kw. 220 volt D.C. generator driven by a single-cylinder reciprocating steam engine, which supplies current for the fresh-water pumping unit, electric refrigerator, and lights. Other auxiliaries include a reciprocating boiler feed pump, a ballast pump, and a combined fire and bilge pump.

The bridge contains a pilot house, captain's stateroom, two crew staterooms, galley, and toilet. A wash basin is fitted in each room, with a locker for each man. The galley, which is used as a mess room, is fitted with an electric refrigerator, oil burning range, table, shelves, and lockers, as well as a mess table and seats.

A twelve-foot metal lifeboat and a life raft are carried on the house top. Also on the house top are two fire hose reels and a 300-gallon fresh water tank. There are two 12-inch searchlights on the pilot house top, and on the navigating bridge are two 10-inch floodlights at each end, for illuminating the tracks at night.

For mooring and handling the car float, 48 inch cleats are located at frequent intervals along the main deck. There is a towing hook at each end, and alloy steel toggle castings for aligning the tracks at the loading bridges. Each compartment of the hull is ventilated by two 12-inch mushroom vents, with tops which may be screwed shut in bad weather. For access to each compartment is a 24-inch watertight scuttle. Two such scuttles are provided in each steering gear space and in the machinery space, with 18-inch vertical ladders. A coaling scuttle is provided for the coal bunker.

The hull form is straight for the most of the length, with the ends cut up to clear the rudder and curved in to fit the loading bridge. This is shown on the lines, (See Fig. 3).

Conditions of Loading.—The first condition of loading investigated was a complete load of thirty cars at an average weight of 125,000 pounds each, with the car float in still water. This is the normal operating condition, but was not found to give a governing bending moment.

The second condition is with the car float at the loading bridge, with eight cars at each end. This would result from having eight cars already stowed at the forward end of the vessel, with eight more in the process of being placed aboard, and standing temporarily at the other end of the car float. This results in the ends being loaded to a greater intensity than the buoyancy at those points, while at midships there is little weight and considerable buoyancy, or in other words, the hogging condition. The bending moment for the riveted design is 20,000 foot-tons and for the welded design 18,300 foot-tons.

This is the most severe probable loading condition, because in this case the cars are taken at a maximum value of 160,000 pounds each, instead of the average load of 125,000 pounds used for the normal operating condition. Load concentration caused by locomotives was not taken into account, because locomotives are not run on the car floats or loading bridges, an intermediate string of loaded or empty cars being used.

The third condition of loading which was tried consisted of the normal loading of thirty cars at 125,000 pounds each, but with the car float in a wave having a length equal to that of the vessel (360′–0″) and a height equal to one-twentieth of the length (18′–0″). This is the standard for the design of ocean-going ships.

The fourth condition was similar to the third, except that the wave was 300′–0″ long and 15′–0″ high. Both the third and fourth conditions gave high bending moments which resulted in scantlings not found in any car float, and, therefore, were not used for design. Such waves never occur in harbors, and rarely in the Cape Charles to Norfolk or Newport News service, and in the event of such waves, there would have been a severe storm, which would have been forecast, and the car float would have remained in port. The run is so short that the vessel would not be caught in any such storm. It may be noted, however, that this design would be able to endure such a condition without damage, as the stresses would not reach the yield point by a good margin.

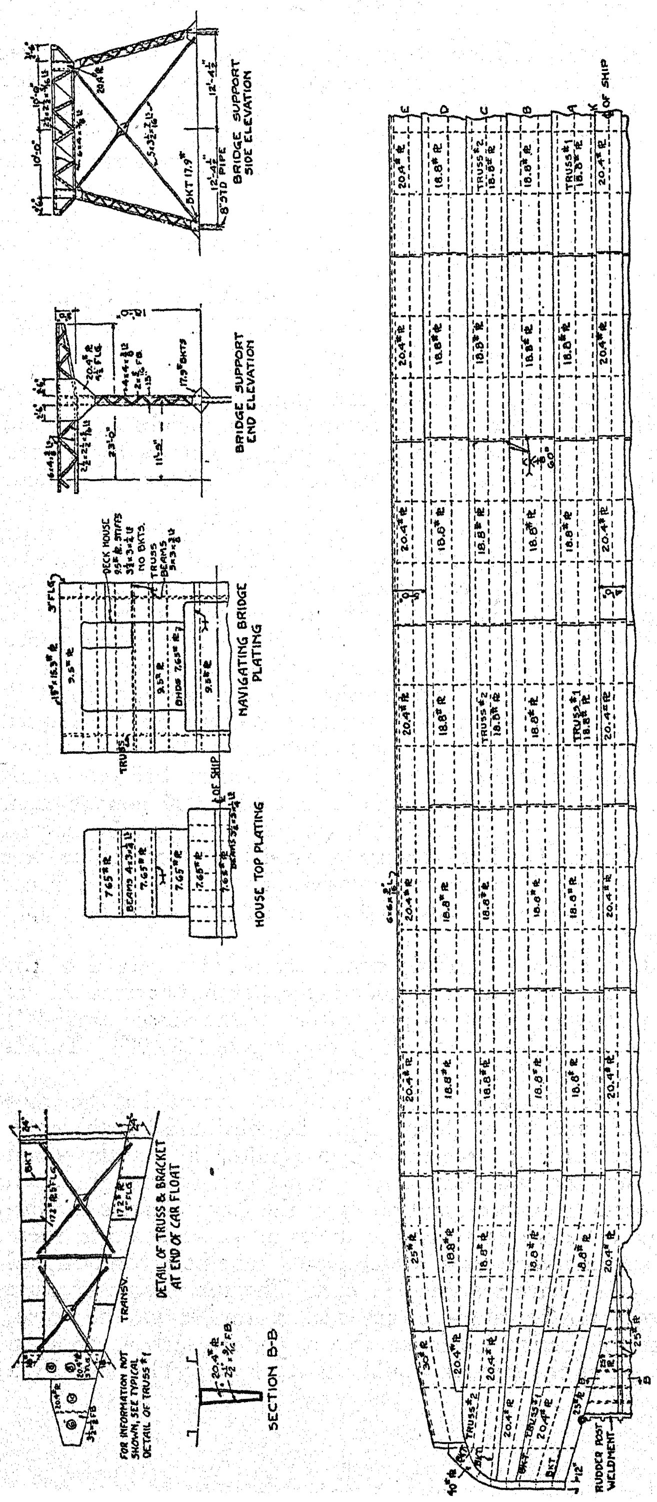

Fig. 2. Structural arrangement of railroad car float—arc welded construction. See also page 347b.

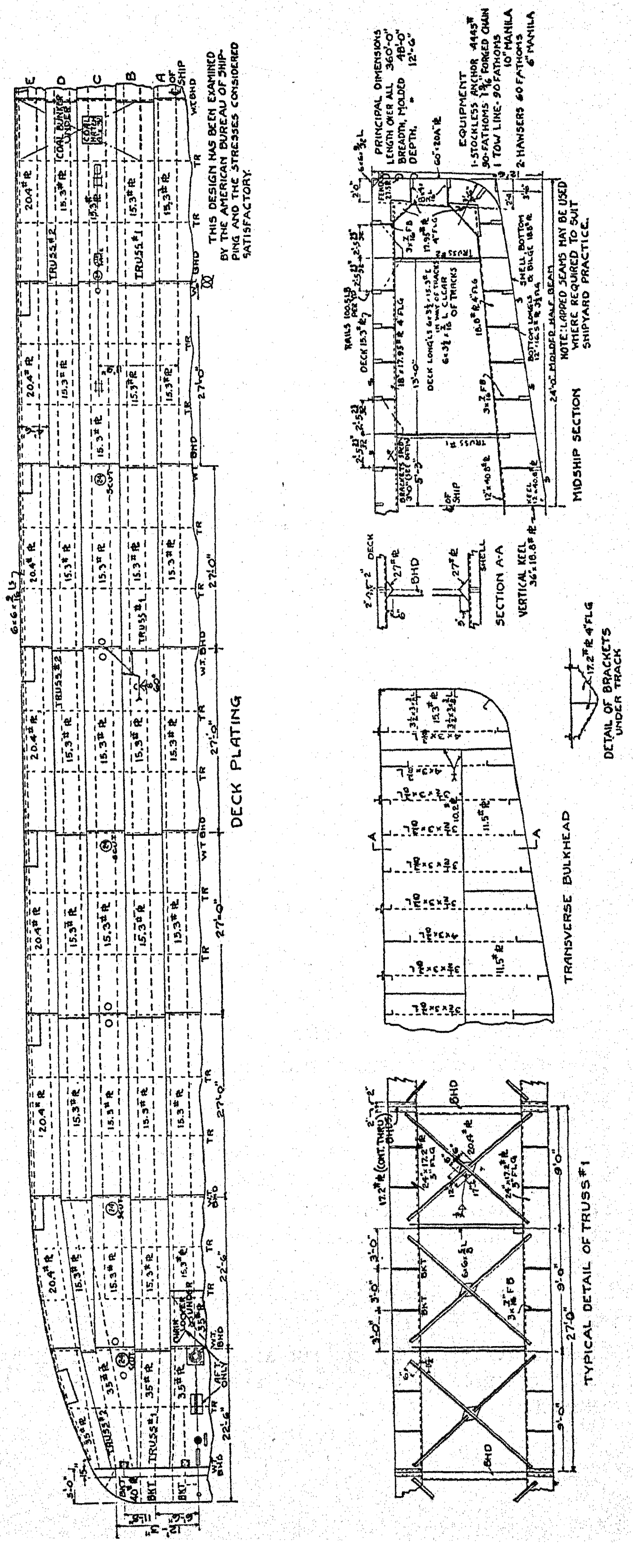

Fig. 2. Structural arrangement of arc welded railroad car float. **See also page 347a.**

The governing condition is therefore the second mentioned, with the car float tied up at the loading bridge, with the ends only loaded, and with heavier than average cars.

Riveted and Welded Sections.—Both riveted and welded sections were designed to give equivalent strength for the design bending moments. Only continuous effective longitudinal members are included in the moment of inertia of the ship as a girder. The calculations with the resultant stresses are summarized in Table 1. All figures here and elsewhere given in tons are in long tons, or tons of 2240 pounds.

TABLE 1—SUMMARY OF LONGITUDINAL STRENGTH CALCULATIONS

	Riveted Section	Welded Section
Displacement, tons	2334	2194
Bending moment, foot-tons	20,000	18,300
Moment of inertia, in^2ft^2	24,964	22,780
Neutral axis above base line, feet	6.70	6.75
Section modulus to deck, in^2ft	4300	3960
Section modulus to keel, in^2ft	3720	3375
Tension in deck, tons per sq. in.	4.65	4.62
Compression in keel, tons per sq. in.	5.37	5.41

Stresses.—These stresses are reasonable for vessels of this type, and as will be noted, they are practically equal, indicating equivalent strength for the two designs, with the same car loading. Allowance for rivet holes on the tension side of the girder is neglected.

Weight Saving.—Figs. 4 to 12 are given as selected comparisons of some of the typical features which illustrate the manner in which the welded construction is lighter than the corresponding riveted design. These diagrams are self-explanatory. Some of the chief sources of weight saving may be summarized as:

(1) Elimination of laps in plating.

(2) Elimination of butt straps and liners in deck and shell plating.

(3) Elimination of faying flanges of angles, by welding the toe of the angle to the plating instead of riveting the heel. In so doing, it is possible to use a lighter angle to give equivalent moment of inertia or section modulus.

(4) Faying flanges of channels not being required, an angle with the same size and thickness may be substituted, with the toe welded to the plating.

(5) Use of flat bar instead of angle stiffeners for webs of girders, etc.

(6) Elimination of angle clips for attaching and connecting adjacent structure. With welding, the members may be directly connected.

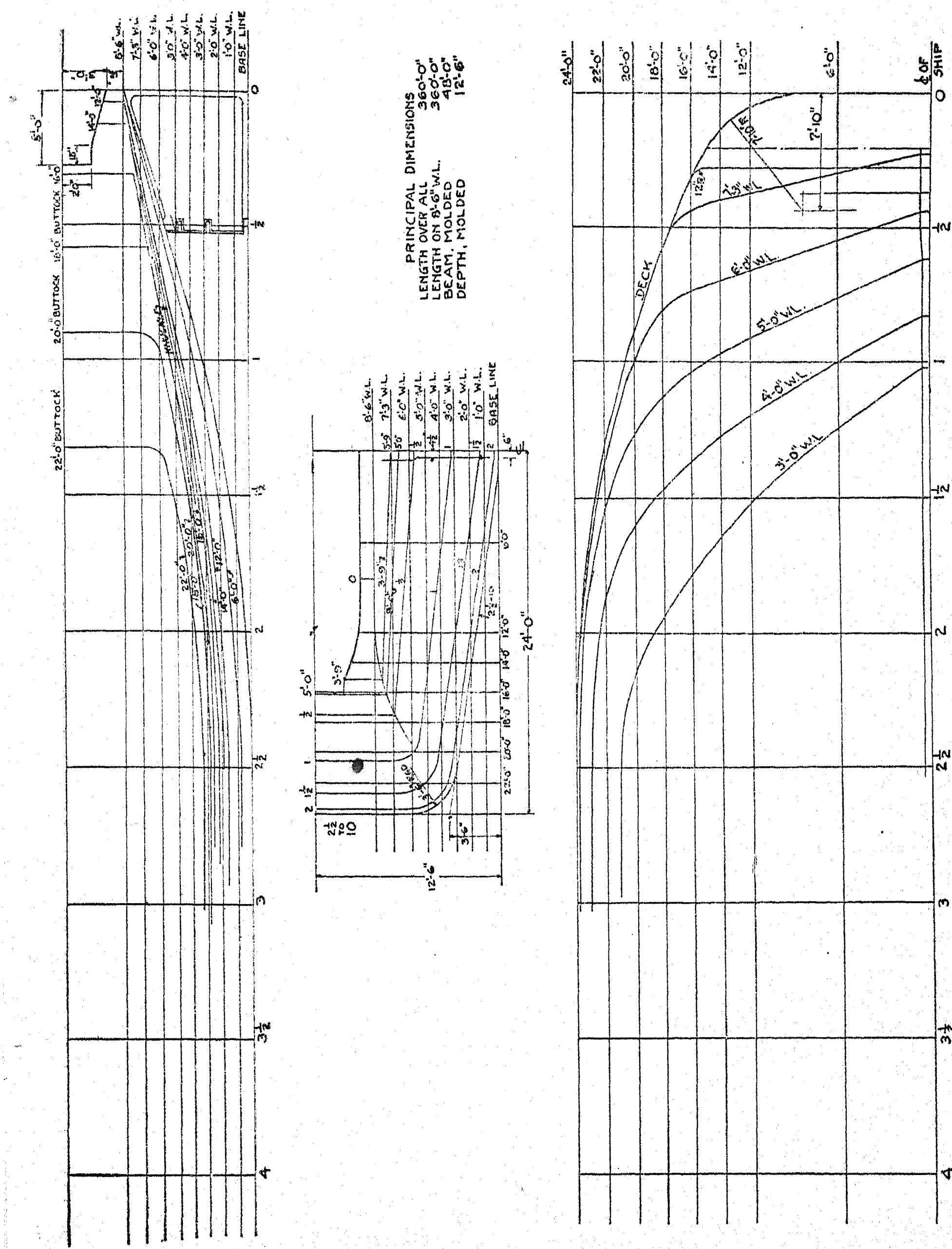

Fig. 3. Lines of railroad car float.

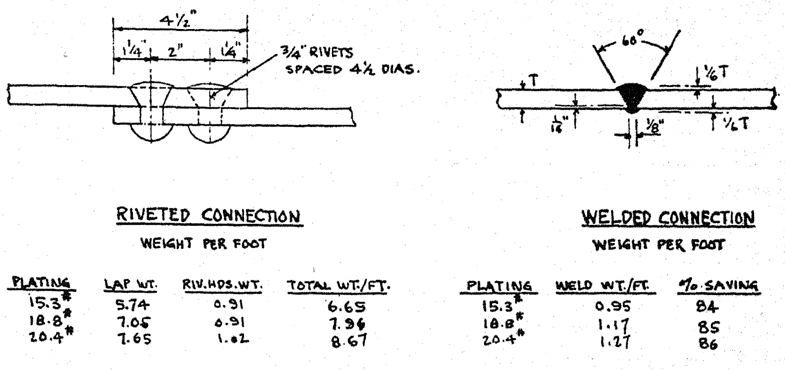

Fig. 4. Comparative weight—riveted and welded deck and shell plating seams.

(7) Elimination of bulkhead boundary angles by welding the bulkhead directly to the deck and shell.

(8) To obtain continuity of the center vertical keel on the riveted design, expensive and heavy anglesmith work is required at water tight bulkheads. This is not required with the welded design, as the center vertical keel may be welded directly to the bulkheads, giving a 100% efficient connection.

(9) For the welded design, smaller brackets to the deck and shell longitudinals are required, as the large depth of the riveted bracket is due to the necessity of getting enough rivets into the connection.

(10) Shorter truss diagonals because of smaller lap required on the truss chords of the welded design.

(11) Smaller gussets at the crossing of the truss diagonals, because of the smaller lap for the welded construction.

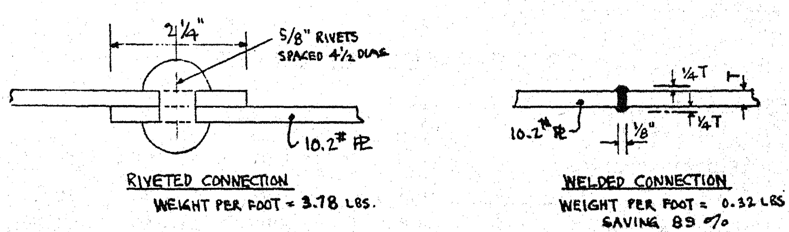

Fig. 5. Comparative weight—riveted and welded bulkhead plating seams and butts.

Detail Weight Calculation.—The weights of both designs were calculated in detail, and are summarized in Table 2. It was found that the welded design has a steel weight 15.6% less than the riveted design, or a total light weight 12.3% less.

TABLE 2—SUMMARY OF STEEL WEIGHT

	Riveted (Gross)	Riveted (Less Holes)	Welded
Plates	1,338,900	1,294,800	1,358,230
Angles	264,420	255,650	151,090
Shapes	217,170	210,220	67,180
Castings	5,600	5,420	....
Pipe	....	....	1,260
Fenders	66,000	63,900	39,000
Weld metal	....	....	20,300
Rivets	49,800 heads	111,900 complete	....
	1,941,890	1,941,890	1,637,060
Tolerance	34,400		29,800
Total steel	1,976,290		1,666,860

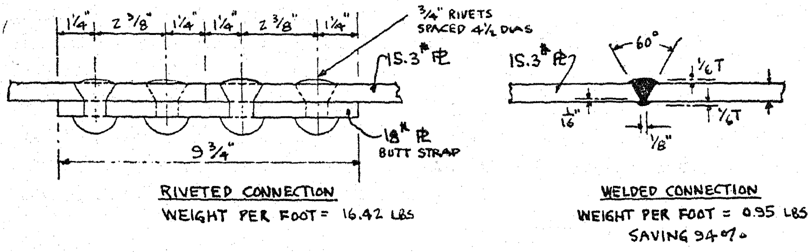

Fig. 6. Comparative weight—riveted and welded deck butts.

Cost Estimate.—Independent cost estimates, given in Table 3, were made for both designs, employing the classifications and units as used by the cost engineering department of the Newport News Shipbuilding and Dry Dock Company.

TABLE 3—COST ESTIMATE

Riveted Design

	Weight	Material	Labor	Total
General charges		$ 22,540	$ 28,620	$ 51,160
Hull	905.0	67,360	68,890	136,250
Wood & outfit	195.0	21,670	11,810	33,480
Hull engineering	34.2	13,050	4,510	17,560
Total	1134.2	$124,620	$113,830	$238,450
Profit 10%				$ 23,845
Total cost				$262,295

Welded Design				
General charges		$ 20,220	$ 26,230	$ 46,450
Hull	765.0	54,750	53,010	107,760
Wood & outfit	195.0	21,670	11,810	33,480
Hull engineering	34.2	13,050	4,510	17,560
Total	994.2	$109,690	$ 95,560	$205,250
Profit 10%				$ 20,525
Total cost				$225,775
Saving for welded design	12.3%	12.0%	16.0%	*13.9%

*By using 1/4" electrode manufactured expressly for flat fillet welds, instead of 3/16" as used, the total saving could be increased to 15%.

General Charges.—In the estimates, "General Charges" include such items as drawings, patterns, molds, docking, delivery expenses, indirect labor, taxes, insurance, and overhead.

Hull Charges.—These include such items as staying, launching, testing of compartments, cementing, rudders, and hull steel. The labor cost for hull steel was determined for the welded construction by analysis of the cost of some work of comparable class recently executed by this company. The labor cost for the riveted design was obtained from a similar analysis of comparable riveted hulls built within the last ten years, corrected for current labor rates. The material cost for hull steel on both designs was obtained by the application of current prices per pound for plates, shapes, angles, etc.

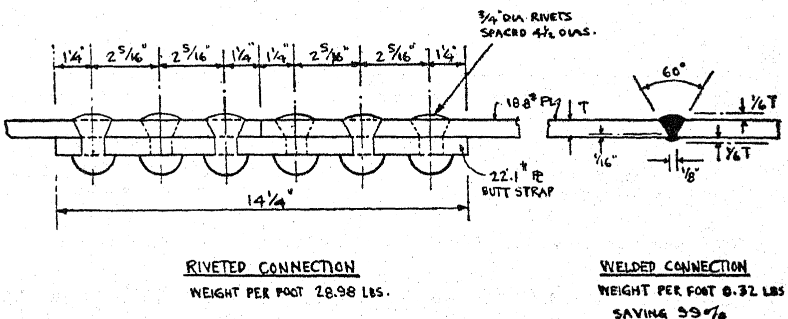

Fig. 7. Comparative weight—riveted and welded shell plating butts.

Wood and Outfit Charges.—Under this heading are included doors, hatches, rails, tracks, rigging, furniture, deck covering, galley equipment, insulation, anchor, cables, navigating equipment, life saving equipment, and many other items. As these do not enter into the consideration of riveting or welding of the main structural hull, they will not be discussed at length. They are the same for both designs.

Hull Engineering Charges.—This item covers machinery such as steering gear, windlass, capstan, pumps, generator, donkey boiler, ventilating system, heating system, fresh and salt water systems,

plumbing fixtures, switchboards, interior communication, and others. As in the case of wood and outfit, they are the same for both designs.

Sub-Assembly.—As will be noted in Table 3, the saving in labor cost for the welded design is 16%. A large part of this is due to the method of sub-assembly of large units for the welded car float. These units are constructed on the skids, and completely welded, with the result that there is a large percentage of flat welding, which is much cheaper than vertical or overhead welding. The only vertical and overhead welding required is that for uniting the sub-assembled panels on the ship.

The units are of the length of one compartment, usually 27 feet (See Fig. 2), and the butts for each strake of deck and shell plating are located six inches from the bulkheads, alternately forward and aft of the bulkhead. This gives a distribution or interruption of the transverse line of welding, and its position close to the bulkhead insures good alignment for welding the panels in place. The deck and shell longitudinals are stopped two inches clear of the bulkhead on each side, to facilitate setting the panels in place, and to provide thorough drainage. The continuity of strength is maintained by brackets of equivalent sectional area which are continuous through the bulkheads, the bulkheads being slotted for the purpose. These brackets are added after the unit has been erected.

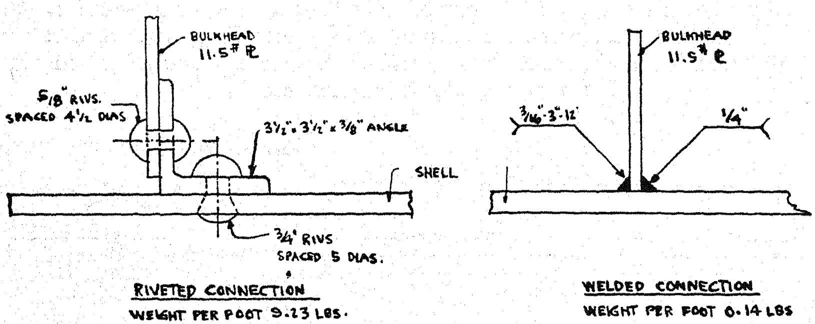

Fig. 8. Comparative weight—riveted and welded connection of bulkhead to shell.

The size of each sub-assembled panel would vary with the equipment for handling large weights at a particular shipyard, but at Newport News, these units would be made up as follows, for each 27-foot compartment length:

(1) Flat keel and bottom shell strakes A, B, and C, complete, with center vertical keel, face plate, bottom longitudinals, lower truss chords, and two transverses. This unit would be about 27 feet long and 48 feet wide, and due to the deep transverses, lower truss chords, and center vertical keel, the panel is stiff enough not to offer difficulty in handling. It would be the first unit to be erected on the ways.

(2) The transverse bulkheads may be completely sub-assembled on the skids, with all butts, seams, and stiffener welding com-

pleted. These units are about 48 feet by 12 feet 6 inches, and are set on the bottom shell panels and tack welded.

(3) Side shell strakes D and E, with three longitudinals, deck stringer angle, fenders, and two side transverses with their brackets, all completely welded into a unit are next put in place. Each of the brackets on the transverses have three holes for erection bolts, to connect with the deck and shell transverses, and hold the units temporarily in place.

(4) The next unit would be a complete panel of deck, with all plating, longitudinals, top truss chords, and two transverses. After these units have been erected and tack welded or bolted into place, the brackets carrying the continuity of the longitudinals are added, as well as the truss diagonals and gussets, and the whole finally welded, using a distributed sequence to avoid distortion and residual stresses.

(5) The special toggle ends of the car float may be sub-assembled as a whole, as well as the skegs, and added to the main portion of the hull.

(6) The vertical bridge legs together with the transverse bridge truss girders make up a sub-assembly, and the longitudinal bridge truss girders similarly, after which the navigating bridge deck plating complete with beams may be added. Then the sub-assembled deck house, complete with house top, is erected, completing the assembly of the steel structure of the vessel.

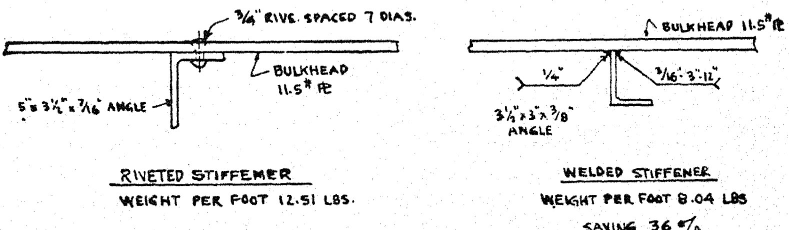

Fig. 9. Comparative weight—riveted and welded bulkhead stiffeners.

Conclusions.—It has been demonstrated in this paper that this car float could be built by welding with a saving in weight of 12.3% and a saving in cost of 13.9%, as compared with the corresponding riveted design. The saving in material cost is due to the lighter construction, by eliminating faying flanges, plating butt straps and seam laps, angle clips, water tight collars, and other items. The saving in the cost of material works out to be 12.0%, and is justified by the fact that the American Bureau of Shipping has examined both designs, and pronounced the sizes of all members and the stresses satisfactory. The saving in labor cost of 16.0% is of course due in part to the reduced weight of steel, but also to a great extent to the system of sub-assembly which makes possible the very extensive use of flat welding, instead of vertical and overhead welding. The possibility of handling these large units or panels in one piece also contributes to the saving

in labor. This sub-assembly method cannot be applied to the riveted car float because of the necessity of staggering the butts in the deck, shell, stringer angle, vertical keel, and other longitudinal members.

The fundamental intention in presenting this cost data is to show the relative saving due to welded construction. Because of the considerable variation in general charges, labor rates, and material prices, the total cost will vary, depending upon the character of the shipyard as well as the time of construction.

The welded car float would be more satisfactory from a service standpoint, as similar riveted car floats have given trouble in service, and have been expensive to maintain, particular trouble having come from the riveting. The welded car float would be more durable and

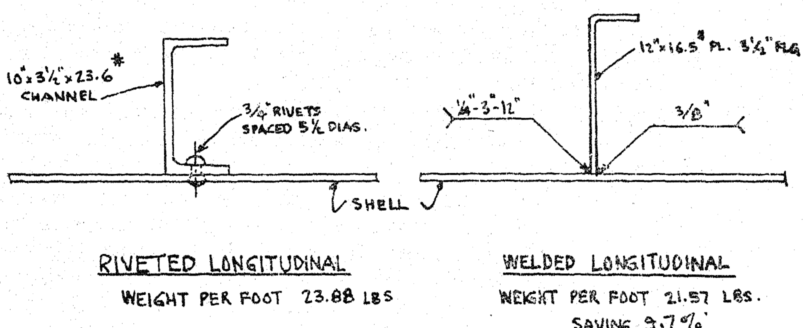

Fig. 10. Comparative weight—riveted and welded shell longitudinals.

economical to maintain, and a longer service life would result from the absence of rivets. The elimination of laps and faying flanges would prevent considerable corrosion in the welded design. Car floats receive very severe treatment in service, and are continually subjected to impact from the tugs, and with piers and loading bridges. Due to the simpler construction, damage repairs are more quickly and cheaply executed, and the welded car float is better able to withstand the severe service conditions than the riveted vessel, due to the freedom from rivets.

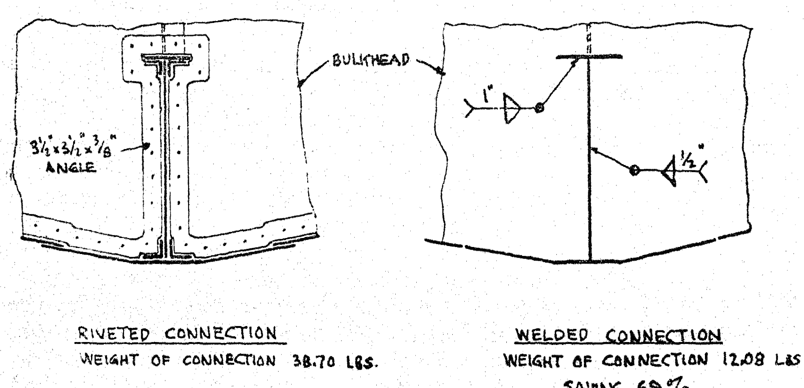

Fig. 11. Comparative weight—connection of vertical keel at bulkheads.

The saving in weight has advantages which may be applied in several ways. Either the horsepower required for towing could be reduced, or with the same power, a higher speed could be maintained. If, however, the horsepower and speed are kept the same for both designs, the welded car float could carry a greater load of freight cars on the same total displacement, and the welded vessel would therefore have a greater earning capacity, which would continue throughout the life of the vessel.

There are in the United States about 600 car floats, averaging about 750 tons each in light weight.

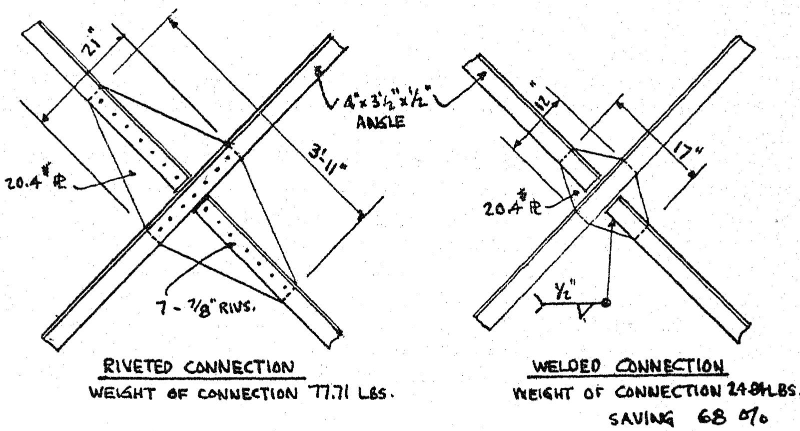

Fig. 12. Comparative weight—truss girder gusset connections.

These would average about 660 tons each if welded, and assuming the cost per ton to be similar to the costs for the car floats described in this paper, a total saving throughout the field of car float construction, if all car floats were welded, could be realized of $13,800,000, together with the same corresponding advantages of greater durability, efficiency, and service life as demonstrated for the car float described in this paper.

While a car float has been adopted to illustrate the practical and proven savings and improvements possible through the use of welding, similar benefits will be obtained if welding is introduced in the construction of other types of barges and vessels of similar type. In principle, at least, these same savings and other advantages will also apply to other types of vessels.

Chapter V—A Design and Method of Constructing Welded Towboat Hulls

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This paper describes the design of an all-welded hull, which is admirably suited for tow and work boats, and the unique method used in constructing two such hulls. This combination of design and construction has proven very economical and has resulted in substantial savings over hulls designed and constructed in the usual manner. The two hulls, already built, are very satisfactory and they will be used as examples to demonstrate the resulting economy and the excellence of the product.

During 1937, Welding Engineers, Inc., of Philadelphia, Pa., constructed the hull of the tug "Vanguard" for Warner Company also of Philadelphia. The dimensions of this hull are:

Length	48′–0″
Breadth	14′–0″
Depth	8′–3″
Displacement	48 Tons

In the early part of 1938 Cruse-Kemper of Ambler, Pa., constructed the hull of the "Termo" for Warner Co. The dimensions of this boat are:

Length	42′–0″
Breadth	12′–6″
Depth	8′–0″
Displacement	42 Tons

The unusual features of these tugs together with the simplicity of detail, and ease of construction which followed, should be of particular interest to all who are concerned with such vessels.

In the spring of 1937 Warner Company was confronted with the necessity of replacing a wooden hull tug boat. In deciding upon a new hull, the choice of steel was based on the superior performance of steel over wood, as experienced in connection with previous hulls both for barges and tugs. Freedom from troublesome repairs, greater strength and the absence of serious leakage all contributed to make a steel hull more desirable than wood. There was little question concerning the use of welding as against riveting, since welding had proven far superior on the grounds of economy, greater scope of details, facility of construction and watertightness. Without welding, moreover, this design would have been impossible as the details used are suited only to welding.

An important item of cost in constructing a hull in the usual manner and with conventional "lines" lies in the mould work required to shape and work the warped plates. The technique necessary for such work is ordinarily found only in a shipyard, but the costs are high. Thus, the first aim in the new design was to plan a hull in which there

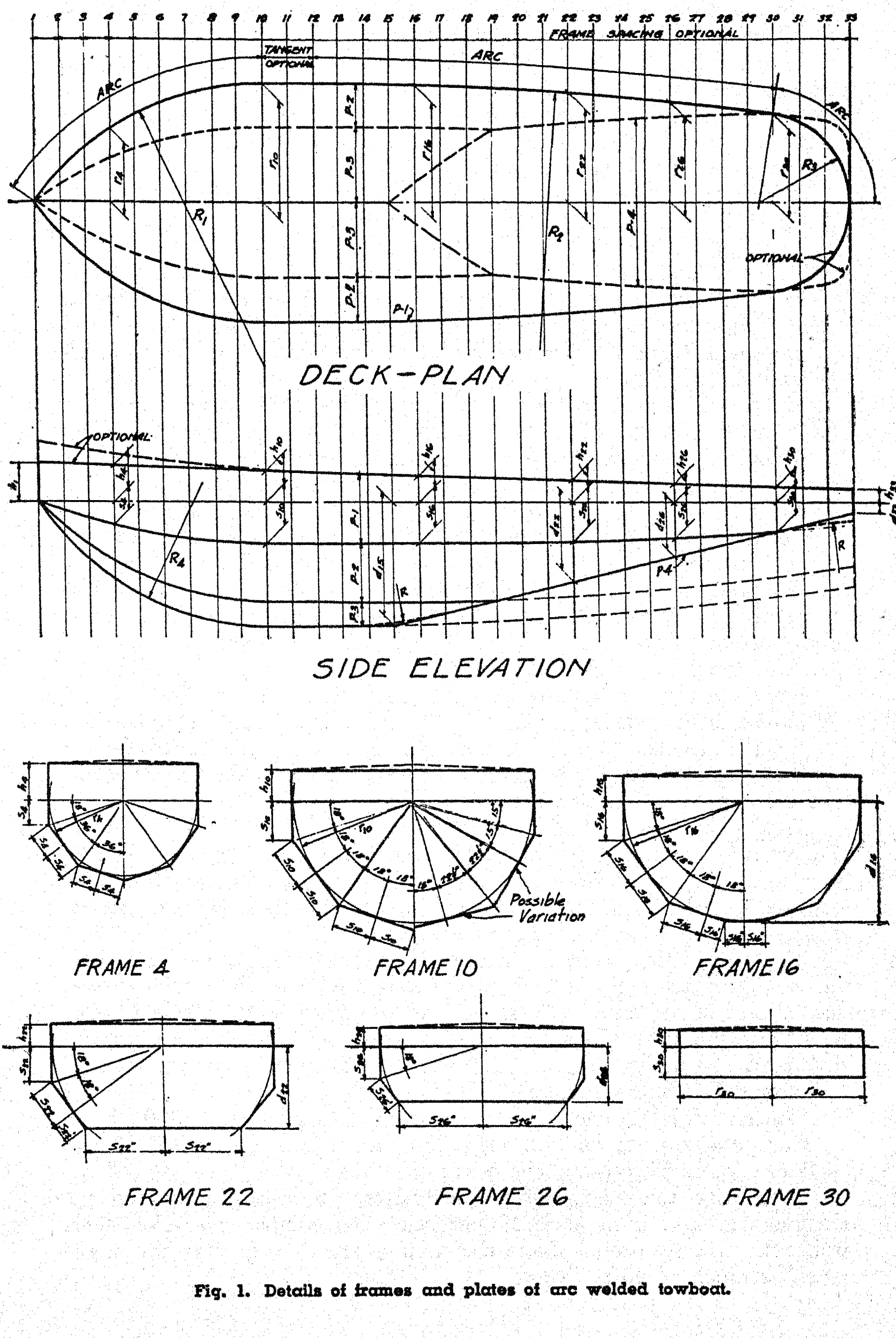

Fig. 1. Details of frames and plates of arc welded towboat.

are no warped plates. By eliminating the warped surfaces and simplifying the details, it was hoped that any competent plate shop could easily construct the hull. This objective was attained and it must be quite obvious that lower costs were sure to follow.

While warped surfaces were eliminated, it was not felt necessary to exclude the rolling of plates since this is an easy process. In the case of the larger hull, no pre-rolling of the shell plates was required as the radii to which they conform were great enough to allow them to be simply pulled down on the frames.

The resulting design is such that all parts can be completely computed and detailed in the drawing-room. In the shop no templates are required as all the work can be laid out directly on the steel. Any experienced structural draftsman and layer-out can successfully complete the details as compared to the more expensive mould loft work. When finished the hull resembles the familiar Zeppelin. With the use of this basic scheme, countless variations are possible to suit the hull to its intended purpose.

As for the actual economy experienced with the two hulls thus far built, let us first consider the "Vanguard". The weight of this boat is 30 tons which includes the hull, hatch cover, pilot house, fuel oil tanks, stern tube and rudder. The contract price for this hull, in the water, was $6,385 or roughly $213 a ton. If we compare this with the cost of a sturdily built wooden hull of like dimensions, we find that the price would be no less than $8,500. This estimate is based on the cost of previous wooden hulls purchased by Warner Company. Now considering a steel hull built with the usual "lines" we find that a conservative figure would be $400 per ton or a total of $12,000 for a 30-ton hull. This gives the following:

Contract for "Vanguard"	$ 6,385.00
Comparable wooden hull	8,500.00
Steel hull with "lines"	12,000.00

This economy depends entirely on the use of welding as without it the design would not have been possible.

Again considering the "Termo", we find that it weighs 18 tons. The contract price for this hull delivered at the waterfront was $4,300 or roughly $240 per ton. This unit price is slightly higher than that obtained for the "Vanguard", but the construction is somewhat lighter which no doubt accounts for the variation.

There is a shipyard in a north central state that specializes in building small welded steel tow boats with the usual lines. Their competitive bid on such a hull as the "Termo", and weighing 19 tons, was $7,400 f.o.b. the shipyard. This figures to a price per ton of $390, which compares favorably with the $400 per ton assumed in comparing the "Vanguard". Thus we have:

Contract for "Termo"	$4,300.00
Competitive price for hull with "lines"	7,400.00

Here again the economy is obvious.

Even with these conservative estimates, the saving compared to the wooden hull is at least 20 per cent. As compared to the steel hull with a conventional shape the savings are even greater and may reach as much as 40 per cent.

As to the possible total savings which would accrue to industry from this design it is difficult to secure any reliable information as to the volume of this business. The department of commerce lists only the registered or documented vessels and it seems that a great many hulls to which this design is applicable would not fall in this category. Small work boats, fishing vessels and the like can also be advantageously built from this design. If we take as a conservative estimate a total of $10,000,000 of such hulls as being built yearly, we have a possible saving at 20% of some $2,000,000 a year.

Design.—The various steps in the design of this type of boat will now be described using several illustrative drawings. In this way it is hoped to demonstrate the exact methods by which the detail drawings can be made, the ease with which the various pieces can be fabricated, and the facility with which the erection and welding can be done. Figs. 1 and 2 are devoted to typical details of frames and plates.

Referring to Fig. 1, we find at the top a typical deck plan. The particular shape shown is only suggestive and can be varied to suit the vessel under consideration. The first step in the design is a tentative selection of a deck plan. Since the shape of the body is a function of the shape of the deck it may later be found desirable to return and vary the deck somewhat until the best combination of body and deck shape is obtained.

In deciding upon a deck plan, it is expedient to first fix the frame spacing based upon structural considerations. With this spacing fixed it becomes possible to select working points that will coincide with a frame center. This is desirable, in that it simplifies the later triangulation.

In the drawing of the deck shown in Fig. 1, we see the forward end formed by a radius R_1, which extends from the bow to Frame 10. From Frame 10 to Frame 12, we have a tangent. This tangent is entirely optional. Following is another radius R_2, extending toward the stern. At the stern the deck can end in a radius such as R_3, or simply have rounded corners.

The next consideration is a selection of a typical cross section. In Fig. 1, there is shown a portion of a regular decagon. Here again a choice is possible, since any geometric figure circumscribed about a circle is permissible. A possible variation is shown in the right half of the section at Frame 10, where an irregular figure is indicated.

With the typical cross section decided, it is now possible to draw all the cross sections, since they are all similar and vary only as the radii of the circles upon which they are circumscribed. It is quite obvious that this radius is the same as the half width of the deck at the frame in question. Since the character of the deck shape makes it possible to readily compute the half deck widths at each frame, such as r_4, r_{10}, etc., we thereby have the radii of the circles upon which the frame figures are circumscribed.

Before completing the cross sections as regards the deck line, however, let us draw up the side elevation. Such a view is shown in the center of Fig. 1. By laying off the edges of each cross section, in relation to the common axis, it is possible to produce the lines these edges or knuckles will form. Since the deck comes to a point at the bow the

side elevation shows these edges meeting in a point on the axis. Toward the stern the edges would also meet at a point on the axis, if projected to the point where R_2, projected, crosses the center line of the deck.

The dotted lines in the side elevation show the shape resulting from a rigid adherence to the scheme, as outlined thus far. It is obvious that such a shape would not allow room for the propeller and rudder. It becomes necessary, therefore to slice off a portion of the body, as indicated by the line which slopes upward towards the stern. Here again it is expedient to select working points which coincide with frame centers.

The drawing shows this sloping line, (projection of a plane), as starting at the nadir of Frame 15 and intersecting Frame 30, at the first knuckle. From here it continues with the same slope upward to Frame 33. It is possible to vary this scheme by introducing a connecting or transforming radius at either or both ends of this sloping line.

The effect that this slicing or truncation has upon the cross sections is indicated in the drawing of the cross sections at Frame 16, 22, 26 and 30. The figures are simply cut off at the bottom. The points at which this cut off occurs is easily determined by reference to the side elevation. Starting at Frame 15, we have d_{15}, as the distance from the common axis down to the intersection of the plane. From the slope of this plane d_{16}, d_{22}, etc., are determined and referred back to the various sections.

Referring again to the side elevation, the deck line can now be established. In general it seems desirable, that this line slope downward towards the stern in reference to the common axis. The drawing shows such a condition with the deck sloping from h_1, at the bow to h_{33}, at the stern. If found desirable, the deck may be sheered up at the bow using a radius as indicated. When the deck is to be crowned, the simplest form is to merely peak it at the center line, with a uniform slope to the sides. In this case, the slope of the peak is first determined and the intersection of the deck and sides calculated, by holding the deck to a uniform slope. This eliminates any warping of plates. Once the deck line is established, the cross sections at all frames become known and are readily calculated, by basing the calculations on the geometric figure selected as the basis. The altered figures at the stern are simply typical figures sliced off at the bottom.

Referring now to Fig. 2, we see the method used to lay out the various plates as P-1, P-2, etc. The frame spacings are first determined by reference to the deck plan with due allowance for the developed length of the arcs between each frame as L_{1-2}, etc. Since the cross sections are formed around a circle, the arcs of each plate are the same. That is to say, the side plate P-1, the intermediate plate P-2, and the bottom plate P-3, all conform to the same radii in the finished hull.

After the frame spacings have been determined, the plate widths can be laid out from a reference line, using the widths determined in the calculations of the cross frames. For example plate P-1, starts at the bow with a dimension h_1, above the reference line and nothing below. At Frame 4, plate P-1 has a width of h_4, above the reference line and a width of s_4 below. We see that h_4, is the distance of the intersection of the deck line and the side plate above the common

axis, and s_4, is the distance of the first knuckle below the common axis.

In laying out plate P-4, the frame spacings are all uniform, due to the fact that the plate has a constant slope with the common axis. The deck plate is simply taken from the deck plan, with due allowance for the increase in frame spacing, caused by any slope in the deck.

It should be evident from this, that all the details are susceptible of accurate calculation and detailing in the draughting room. The claim

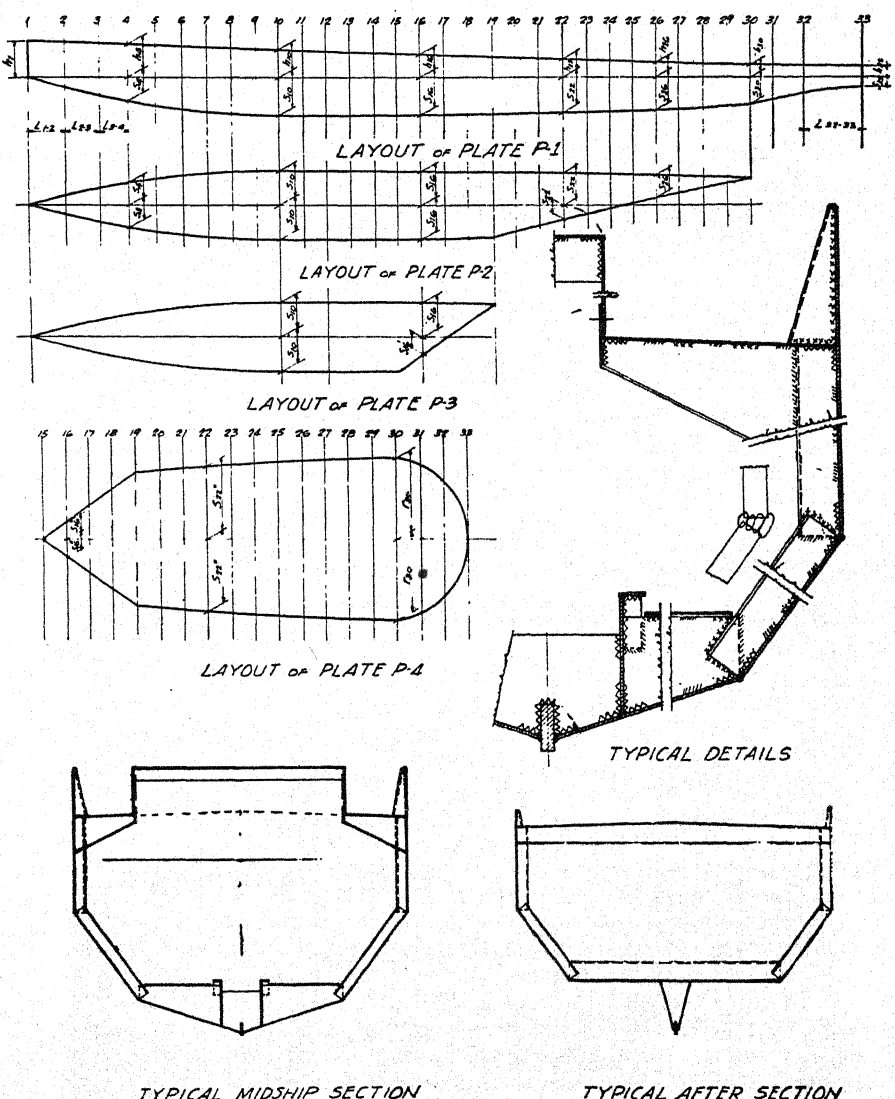

Fig. 2. Layouts of plates and details of typical sections of arc welded towboat.

of economy for this hull is based upon the fact that with proper detailed drawings, the construction becomes feasible in any shop familiar with structural or plate work.

The procedure of constructing the hull is first to prefabricate the various cross frames. The members of each frame are cut and laid on a working platform or bench and welded together. As the frames can be shifted easily, each weld can be run with the work in the most advantageous position, and downward welding is possible for all joints.

Next the deck plate is cut to shape and as it will probably be made up of several pieces, it can be welded together on the blocking used to support the hull during erection. Downward welding is again possible. With the deck plate ready the cross frames are set in place upon this plate.

This is quite different from conventional methods of shipbuilding where the hull is erected upright. Here the hull is substantially completed in the inverted position. The cross frames are securely welded to the deck, with intermittent fillet welds, again run downward. Once the frames are in place the keel bar is inserted and welded. Then the side plates are erected by tacking them to the cross frames. If the radii of these plates are small, it may be desirable to roll them before erection, but if the radii are great, rolling will not be required. The continuous fillet weld on the inside, between the deck and side plates, is run at this time.

Next, the intermediate hull plates are erected followed by the bottom plates. Each of these plates is tacked to the frames, but the outside welds on seams at the knuckles are completely run while the hull is inverted.

With all the plates in place the hull is righted. It is easy now to complete the welding on the inside. The knuckle joints or seams are

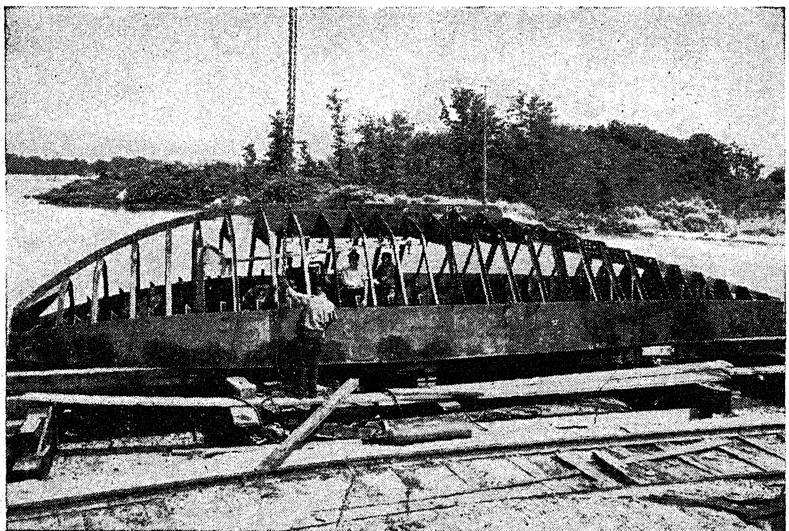

Fig. 3. Construction view of towboat—shop-fabricated cross frames in place.

given one pass and the connections between the frames and the side and bottom plates are completed.

In this manner, practically all the welding is downward, which results in economical, sound welds. The stern tube, rudder, deck house, etc., can be attached without difficulty and the boat completed.

Construction.—Fig. 3 shows the shop fabricated cross frames of the "Vanguard" set in place on the deck plate. The keel bar aids in holding the frames in alignment. The workmen are erecting the side plates. Intermittent fillet welding was used to attach the shell plating to the cross frames. This hull, being too large to ship by rail, was assembled on the shore of the land-locked lake in which it now operates. By erecting the hull bottom up, the greater portion of the welding could be done in the downward position.

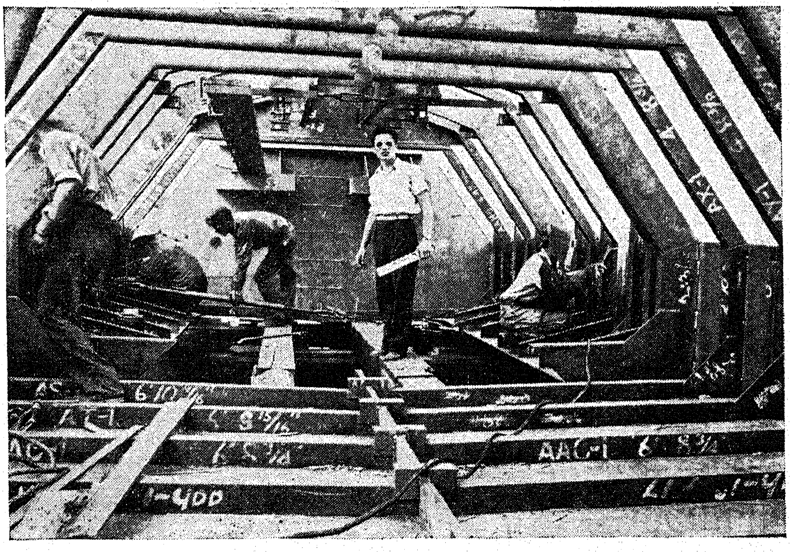

Fig. 4. Construction view of towboat showing framing.

Fig. 4 is an inside view of the "Vanguard", and the workmen are standing on the under side of the deck. The watertight bulkhead at Frame 5, is clearly visible. The two boxes attached to the bulkhead, which are now inverted, will eventually hold the storage batteries. As can be seen, some of the frames were constructed of structural angles, while every so often a deeper flanged plate was used. The welders are shown attaching the side plates to the cross frames. Note how accessible the work becomes with this scheme of erection. A steamboat ratchet was used to pull the side plates against the frames.

While the hull is in the position shown in Fig. 4, the seams in the plating are welded on the outside, using as many passes as necessary to build up to the thickness required for the various plates. The plates are torch cut with square edges and the angle at which they intersect forms a convenient V for welding. Downward welding is possible in

practically all of these operations. In order to hold the plates in place they are tacked to the cross frames and later, when the hull has been righted, the finish welding is done from the inside. In constructing a hull in the upright position, as is usually done, the bottom plates are applied to the ribs or frames from beneath, but here, with the hull bottom up, the plates are laid on with great ease.

When the hull plates have been assembled, (See Fig. 5), the boat is ready to be righted. As can be seen, the "Vanguard" has no waist.

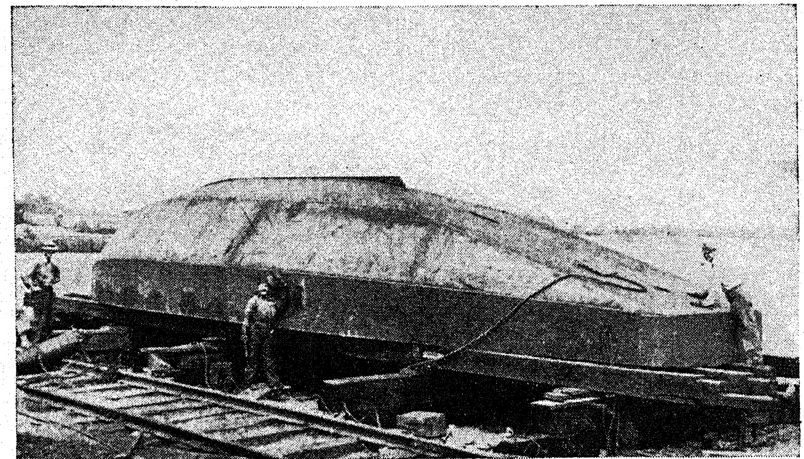

Fig. 5. Plating applied, boat ready for righting.

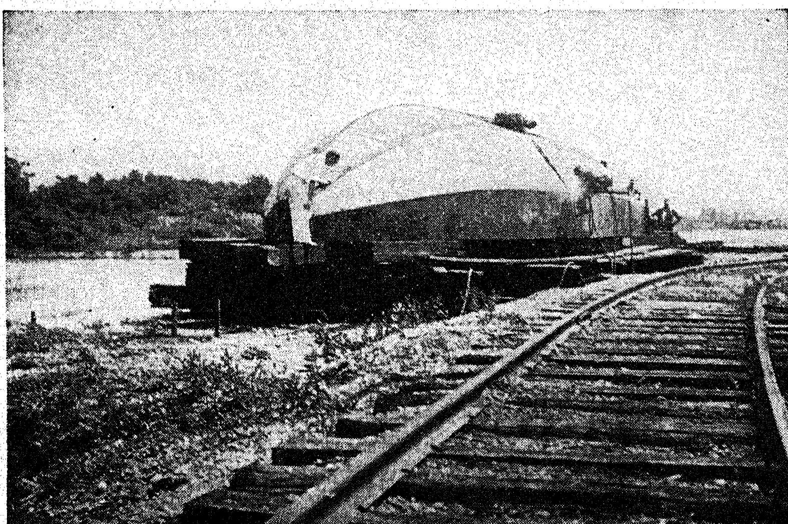

Fig. 6. Bow of towboat resembles a Zeppelin.

If a waist had been desired, the side plates could have been extended above the deck line, in which case the blocking could not have extended beyond the limits of the deck. The holes in the sloping plate are for the stern tube and rudder shaft which were erected later. A cutting torch and welding machine is practically all that is needed with the exception of small hand tools.

The resemblance to the familiar Zeppelin is apparent when the hull is viewed from the bow, (See Fig. 6). There are no warped plates to contend with in this design, they are merely rolled in one direction. No pre-rolling was necessary with the "Vanguard" as it proved easy to pull the plates down onto the frames. Here we can see the keel bar extending up between the two bottom plates. The bow was not brought to a point, but left blunt, as it was felt this shape would prove more serviceable for occasionally nosing the barges around.

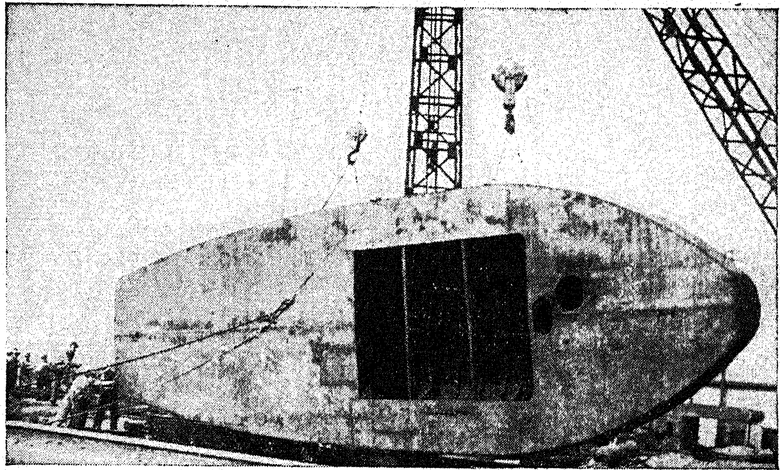

Fig. 7. Righting the hull by means of cranes.

Once the shell plates are attached, the hull can be righted. (See Fig. 7). Here we have two locomotive cranes turning the "Vanguard" and, incidentally, giving us a good view of the deck. Two temporary struts can be seen spanning the engine hatch. Directly forward of the hatch is an opening which will afford an emergency exit from the engine room. The other opening leads to the forward watertight compartment. On the "Vanguard" this fore peak tank, which holds about one thousand gallons, is used as a cooling chamber in the closed circuit cooling of the engine.

Now we have the hull right side up and the plate seams can be worked on from the inside. The connections to the cross frames which were previously tacked are now finished. The sloping stern plate makes room for the propeller and rudder. The next step was the attachment of the stern tube, deadwood and rudder followed by the engine hatch cover and deck house.

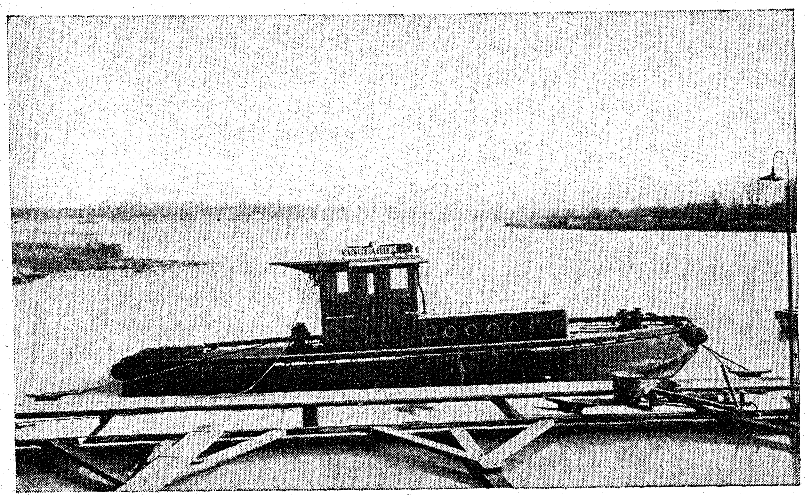

Fig. 8. Arc welded towboat "Vanguard" in service.

Fig. 8 shows the "Vanguard" in service. The rail was constructed of 6″ x 6″ oak, set up on pieces of channel. The canopy at the after end of the deck house protects the men while engaged in manipulating the lines at the stern bitt. Powered by a 150 horsepower diesel engine, this tug shuttles barges back and forth from the dredge to the screening plant on the land-locked waters of the Van Sciver Lake of Warner Company. It has proven admirably suited for this type of service.

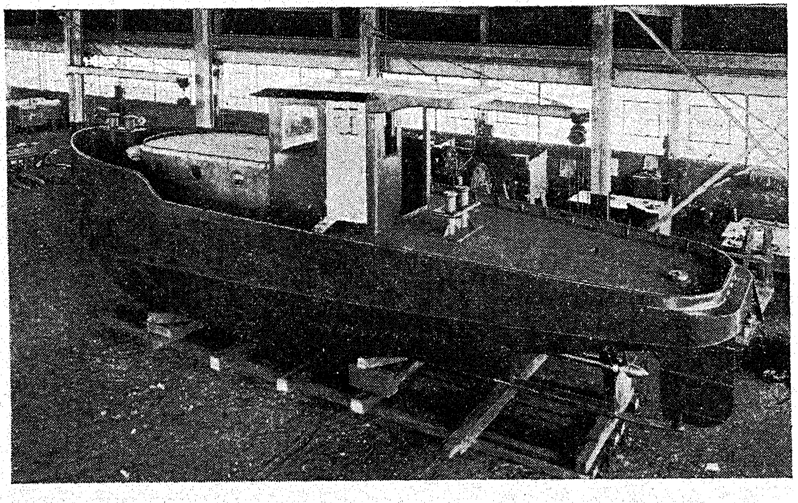

Fig. 9. Arc welded towboat "Termo" completed.

The tug "Termo" was built in the shop of Cruse-Kemper Company at Ambler, Pa., and shipped by rail to the Delaware River. Fig. 9 shows

the boat in their shop just before being loaded for shipment. Like the "Vanguard" it was constructed bottom up and then righted by the shop crane. In the bow we see the waist formed by extending the side plates above the deck line. Note the welded bow and stern bitts. The engine hatch cover is attached by bolting to allow its removal for installing the engine. The deadwood, propeller strut and rudder are clearly shown. This boat is used by Warner Company for shifting barges at their terminal plant where the sand and gravel is transferred from cars to the river barges.

Timber has been driven from the field, in the case of large vessels, because of structural strength and other requirements. By reason of its economy, however, it has retained a foothold in the case of smaller hulls. From a marine standpoint, steel is much superior to timber for the construction of hulls. Now with this design it becomes possible to build a steel hull cheaper than one of timber. Since the design, as developed thus far, does not give promise of being applicable to vessels of high speed it must be considered only for such boats as tugs, work boats, etc., where the speeds are moderate. With this, then, it is possible to build a better article for less money and it would seem that a social service is thus rendered.

The "Vanguard" and "Termo" both perform exceedingly well. They handle with ease, turn in a radius not much greater than the length of the vessel and yet follow a course steadily. The maneuvering qualities of the boats are excellent. Both are equipped with diesel engines for propulsion and promise to give many years of satisfactory service.

The "Vanguard", constructed by Welding Engineers, Inc., was too large to be shipped by rail and was therefore assembled on the shore of the Van Sciver Lake of Warner Company. This lake is land-locked and is formed by the excavation of sand and gravel. The frames were all prefabricated in the shop and trucked to the site a distance of some twenty-five miles. The hull plates were shipped to the site as rectangular plates and flame cut to size as needed.

The "Termo", being of smaller dimensions, could be shipped by rail and was therefore entirely constructed in the shop of Cruse-Kemper at Ambler, Pa. It was, likewise, constructed bottom up and in this case the hull was righted by the overhead shop crane. Cruse-Kemper specializes in the construction of gas holders, but had no difficulty whatever in handling this hull. This seems to indicate that the intentions of the scheme to design a hull capable of construction by any shop familiar with plate work has been realized.

Chapter VI—Welded Wharfboat Built from Six Obsolete Steel Barges

By C. Perry Streithof,
Structural engineer, Dravo Corp., Pittsburgh, Pa.

One of the leading advantages of welding is that it is economically adaptable to the alteration of existing steel structures for new purposes.

An outstanding application of this function was the construction of one of the largest steel hull wharfboats on inland waters.

The wharfboat, (See Fig. 1), was built by the Dravo Corporation, of Pittsburgh, for the Greene Line Steamers, Inc., Cincinnati, and was constructed entirely by welding, using six obsolete sand and gravel barges for the hull of the new unit. Built and launched at Neville Island, the boat was towed to its location at the foot of Main Street, Cincinnati, where the steel superstructure was completed by installing the siding, roofing, doors, etc., and the boat was placed in service in the early part of July 1937, after surviving, without damage, the record flood of January.

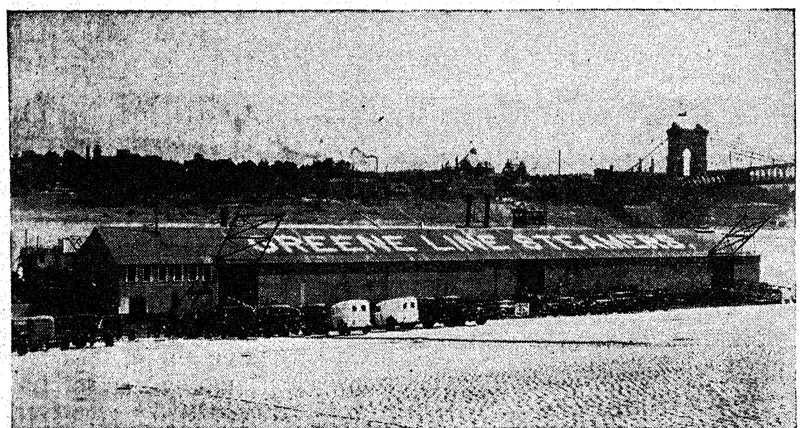

Fig. 1. Wharfboat built by arc welding of steel salvaged from six obsolete barges.

The barges used in constructing the hull were built by the Dravo Contracting Company in 1915 for the Keystone Sand and Supply Company of Pittsburgh, and were used by the latter company in the sand and gravel trade. They were 135′-0″ long, 27′-0″ wide, and 7′-6″ deep at the side. The framing consisted of a water-tight bulkhead at each rake end, three longitudinal trusses, four transverse trusses, and transverse frames spaced 30″ centers between the end bulkheads. The rake ends were of the "sheep nose" type and framed longitudinally at 30″ centers. A cargo box 110 feet long and 21 feet wide was located on the

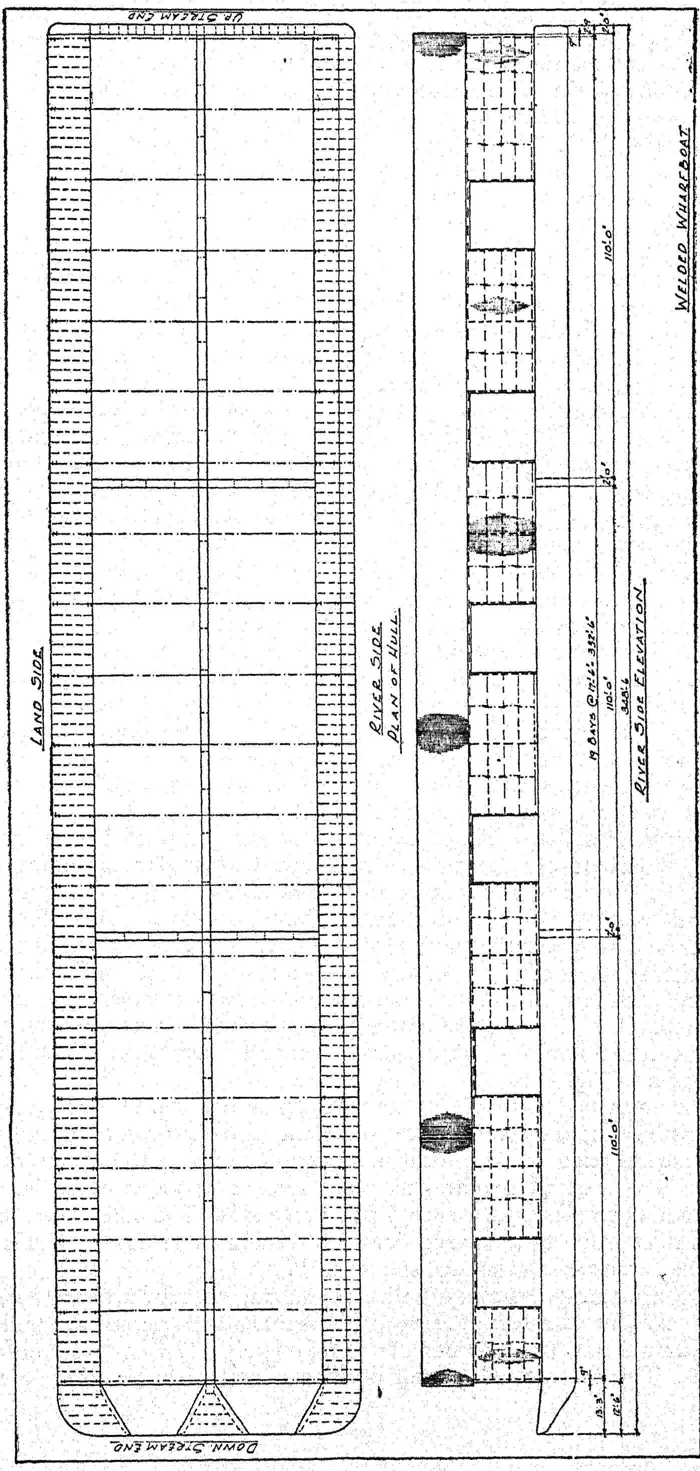

Fig. 2. Plan and elevation of arc welded wharfboat.

deck, with a concrete floor covering the steel deck in the cargo box area.

Notwithstanding twenty years of service, the barges were found to be in good condition. A thorough survey of the barges indicated a corrosion reduction averaging only 9% on the deck plating, 13.7% on the bottom plating, 13.3% on the sides immediately below the gunwale and 16.6% at the bilges. Structurally the deck, bottom, and longitudinal framing between the rake bulkheads were in exceptionally good condition. The side frames indicated considerable "bowing", and the side plating indicated "ribbing" at the frames. This was due to the numerous bumps received during its long service. The sides at the rake ends were in relatively poor condition due to the same cause. While this structural distortion would have ultimately become acute had the barges remained in heavy river traffic, it was considered unimportant for the service conditions to which the contemplated wharfboat would be subjected. Of more importance from the barge owner's viewpoint was the fact that due to the "sheep nose" shape of the rake ends, these barges when combined in a tow, permitted large openings in an otherwise continuous deck, resulting in less efficient operation and creating a safety hazard.

There were two potential purchasers, one willing to dispose of his obsolete barge equipment and purchase new, the other ready to take advantage of a sound bargain providing the used barges could be adapted to his particular requirements. Through the use of welding the problem was simplified and the wharfboat became a reality.

The cargo boxes were removed from the barges, and the rake ends were cut off except on one end of two barges; they were then placed in two parallel lines of three barges each with a two-foot separation between all units, after which the six sections were joined by welding into one large hull with a width of 56 feet, a length of 348′-6″, and a depth of 7′-6″. The general arrangement of the hull is shown in Fig. 2, and a typical transverse section through the boat is shown in Fig. 3.

The longitudinal splice, connecting the two lines of barges transversely, consisted of a continuous deck and bottom plate spanning the two-foot space between the adjacent barges, and welded continuously to the shell plating. Vertical diaphragms were used to transmit shearing stresses and to prevent weaving of the barges under unequal loading conditions. These diaphragms were placed opposite each end bulkhead, opposite each line of transverse trusses, and midway between each transverse truss line. The vertical plates were cut with an acetylene torch to suit the contour of the barge sides. Details of the longitudinal splice are shown in Fig. 4.

The construction details of the two transverse splices were treated differently. The transverse splice connecting the upstream barges to the intermediate ones, was identical in design features to the longitudinal splice. The vertical diaphragms were located opposite each line of longitudinal trusses, and at each inside barge side. The outer sides were plated to conform to the barge sides and welded water-tight. Details of this fixed transverse splice are shown in Fig. 5.

The remaining transverse splice connecting the downstream barges to the adjacent pair, was built in such a manner as to permit the hull to be separated into two sections of approximately 112-foot and 236-foot lengths. This feature will permit docking if and when required, as the

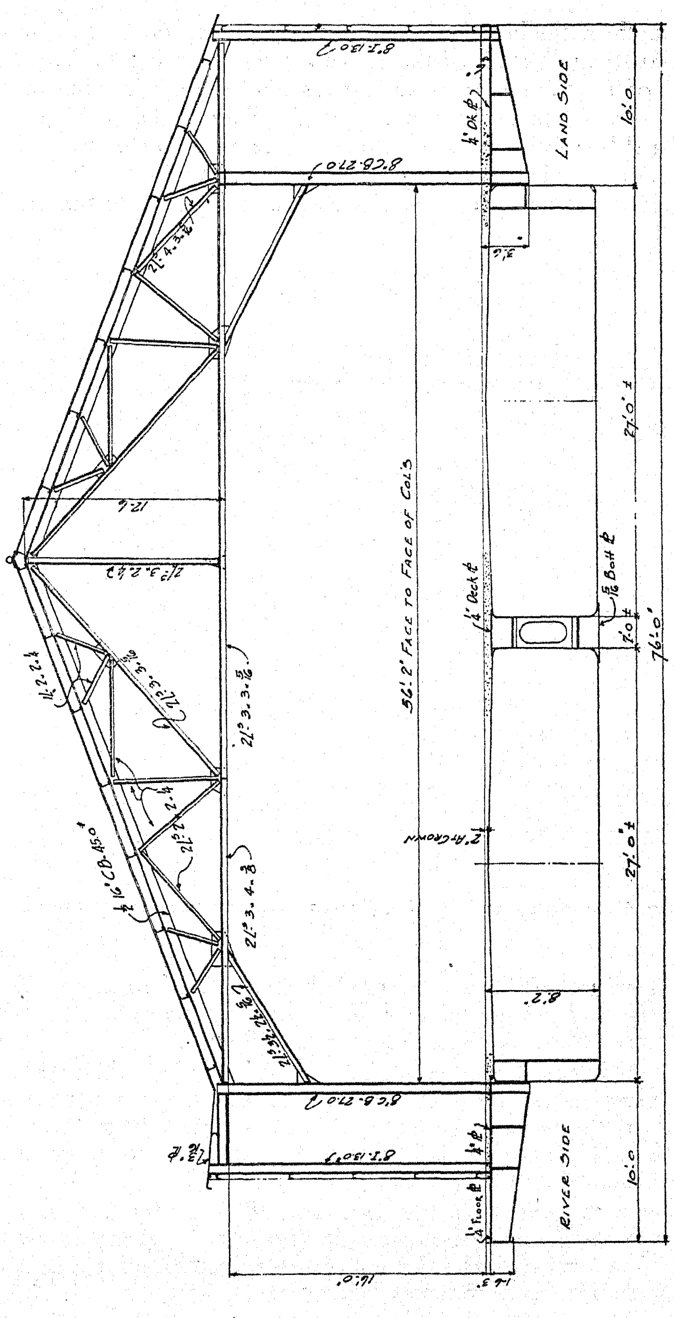

Fig. 3. Typical transverse section of arc welded wharfboat.

total length of the boat is longer than any present docking facilities on the Ohio River. Details of this splice are shown in Fig. 6. The bottom plating of the downstream barges was burned off approximately 20" beyond the end bulkhead forming a false bottom and preventing logs or other debris from jamming into the space between the two end bulkheads. An inner bottom, located slightly above the light-draft water line was welded water-tight on a pair of shelf angles welded to the end bulk-

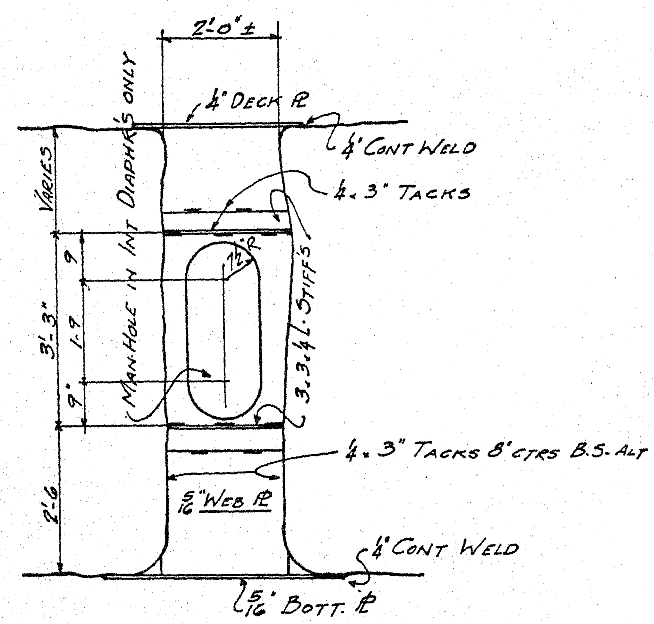

Fig. 4. Details of longitudinal splice connecting the two lines of barges.

heads. Fore and aft brackets were placed inside the barges, opposite the diaphragms to distribute the loads to the framing. The diaphragms were bolted to permit quick dismantling of the two units.

The four downstream barges were joined together while docked on marine ways. After this unit was placed afloat, the remaining pair were brought on the ways and spliced. The two lengths were then joined while afloat. This work as well as all of the remaining erection was done from the outfitting dock.

In order to secure a greater deck area, platforms ten feet wide were bracketed out on each side of the hull, (See Fig. 7), giving a total deck width of seventy-six feet. Except for the location of the outboard columns, the river-side brackets are identical with those on the land-side. The brackets were spaced 30" centers, and consisted of a ¼" vertical web plate welded at the top side to the ¼" deck plate, and having a 5" x ⅜" bar welded to its lower side to provide flange material. The web

plates were cut to conform to the barge sides and welded into position. Two pairs of vertical stiffener bars 2″ x 3/8″ were provided as indicated on the drawings.

The inside of the hull was reinforced with a vertical bracket opposite each column. This bracket consisted of an 18″ x 5/16″ flanged plate having a 3″ flange. The unflanged side was cut to suit the barge side and welded. Additional welding connected the bracket to the deck and

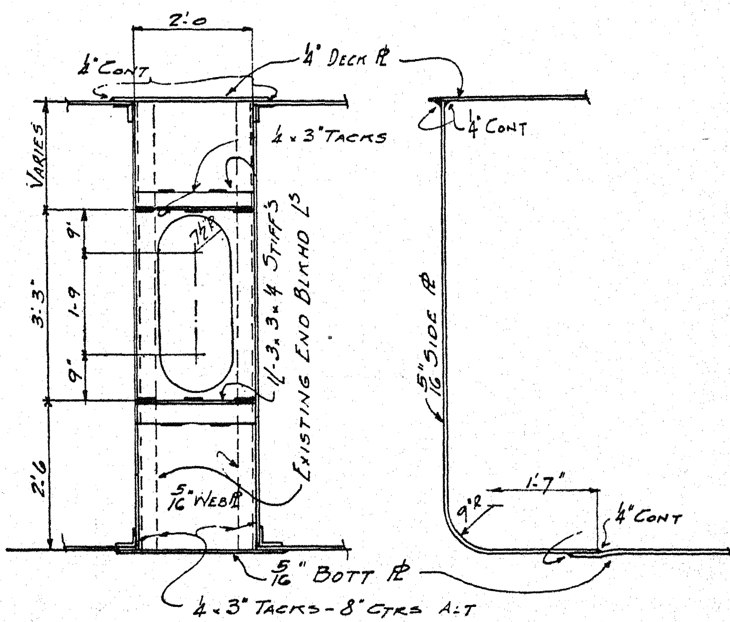

Fig. 5. Details of fixed transverse splice.

bottom plating. A pair of diagonal angles added to two transverse frames in each 17′-6″ bay provided additional reinforcement to the barge sides. The loads from the brackets were distributed to these reinforced frames by means of a continuous flanged plate 12″ x 5/16″ welded to the barge sides in line with the bottom flange of the brackets.

Provision was made for the installation of three gangways on the landside. The brackets at the columns were provided with a pin hole at the outside end, about which the gangways were hinged. These brackets were built of 1/2″ web plates, with 8″ x 5/8″ top and bottom flange plates welded to the web. Two pairs of 3 1/2″ x 3/8″ stiffeners were provided with additional stiffening directly under the outboard columns. The top or tension flange was spliced at the deck line with adequate tie plates. Intermediate loading platform brackets consisted of 3/8″ web plates, 6″ x 1/2″ top and bottom flange plates, and 2 1/2″ x 1/2″ stiffener bars. The interior hull reinforcement brackets opposite the columns were built of

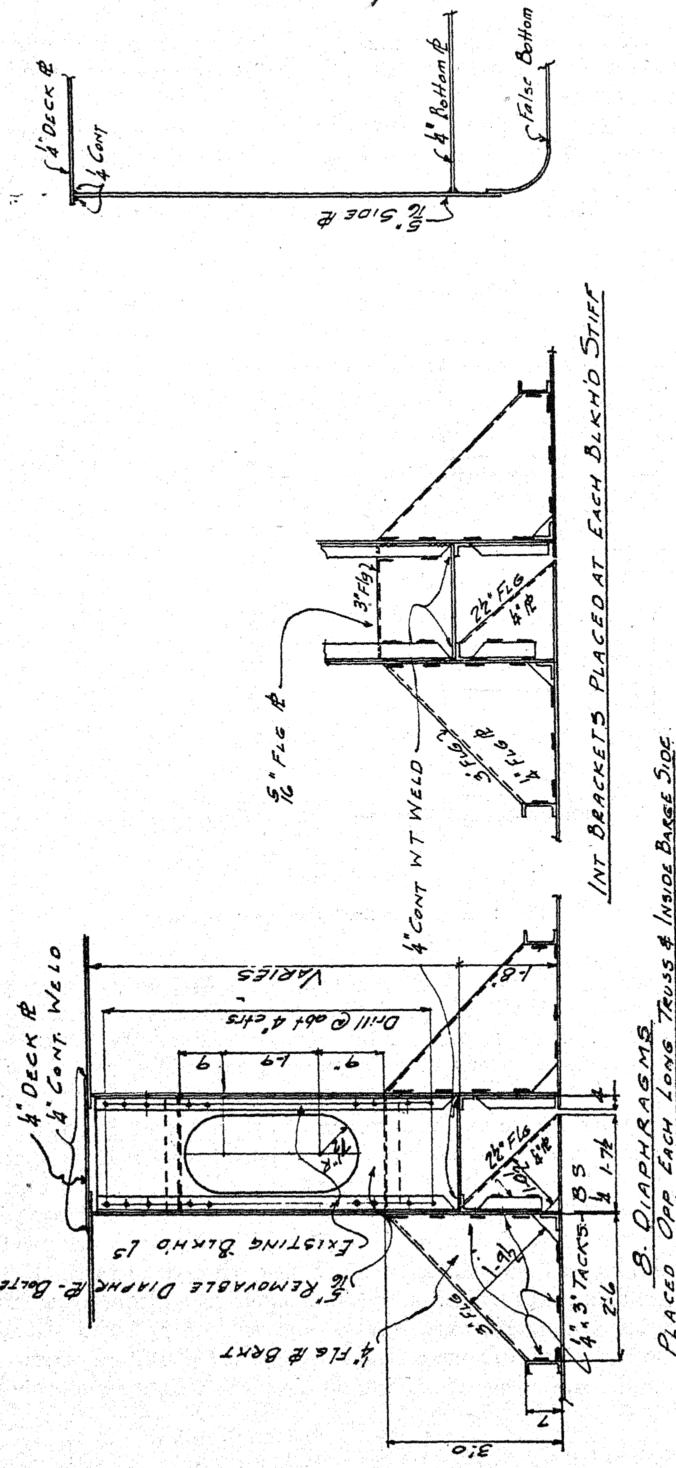

Fig. 6. Details of fixed transverse splice with removable joint.

24″ x 3/8″ web plates, and a 7″ x 1/2″ flange plate on the one side—the hull side plating providing the other flange material.

The upstream end of the hull was provided with a new rake end, extending two feet beyond the end bulkhead. The shell plating for this extension was 5/16″ thick, and the framing consisted of twenty-four vertical diaphragms equally spaced across the width of the boat. Deck stiffening bars were placed beneath the deck fittings and framed into the vertical diaphragms. The deck of this extension was used as a walkway across the end of the boat.

As mentioned previously, the downstream rake ends were not removed from that pair of barges. Deck plating 1/4″ thick, supported on brackets, joined the side extensions to the rake ends. The open portion between the two adjacent rakes was also decked with 1/4″ plating supported on flanged plates framing into the rake side. A 12″ x 1/4″ fascia plate trimmed the perimeter of the deck extensions.

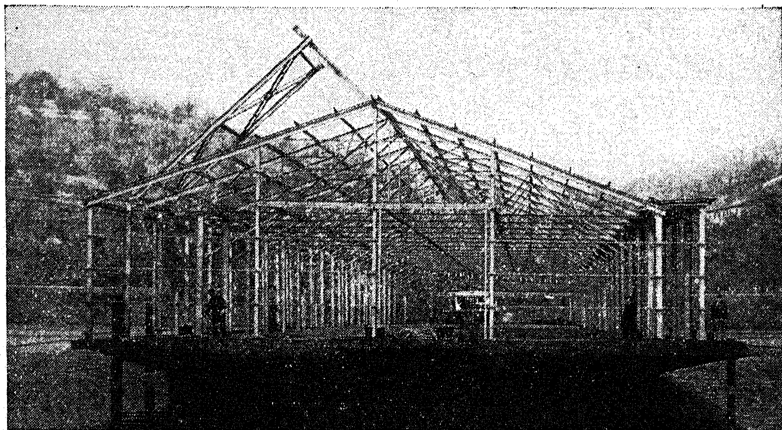

Fig. 7. End elevation of arc welded wharfboat showing superstructure.

An all-welded superstructure covers the entire deck area with the exception of the rake ends and a four foot walkway on the river side. The general design is indicated on the transverse section shown in Fig. 3. A derrick supported from the roof-structure is used for handling the gangways on the land side. The main columns of the transverse bents are connected to the barge sides through fairing plates, which function to align and plumb the columns. These pieces were built of channel-shaped flanged plates, the flanges of which were trimmed to suit the irregular surface presented by the barge sides. Details of these column connections are shown with the platform brackets in Fig. 6. The roof and side framing follow standard mill-building practice.

Of special note is the six foot lean-to on the river side. The original design called for the river side of the building to be flush with the main columns, with a four-foot walkway bracketed out from the barge sides. The six-foot additional extension was not considered by the purchaser until the superstructure was practically fabricated. Through welding,

this revision in design was simplified to the point where all of the partially fabricated material was utilized.

The total cost, to the purchaser, of the hull and superstructure framing afloat Neville Island was $47,223. This figure is composed of the following items:

6-Used barges	$12,000.00
Alterations, reinforcement, splices, and extensions to hull, 164 Tons	22,100.00
Total Cost of Hull	$34,100.00
Superstructure, 139 Tons	13,123.00
Total Cost of Structure	$47,223.00

Comparing the above hull cost with a new hull designed to meet the same requirements, we have:

Estimated cost of new hull, 550 Tons @ $135	$74,250.00
Cost of rebuilt hull as above	34,100.00
Total saving through salvage of barges	$40,150.00

The general design of the new hull on which the foregoing estimated cost is based, and follows modern welded hull practice. Our experience has been that the cost of a comparable riveted hull would average from ten to fifteen per cent more. A similar saving was realized in the welded construction of the superstructure. It is the purpose of this paper, however, to demonstrate the salvage feature of welding technique. Obviously, the cost of uniting the six barges into an integral, water-tight, and rigid hull would have been prohibitive if riveted splices and connections had been employed, due to the irregularities of the surfaces which were to be connected. Therefore the entire saving of 54% of the cost of a new hull can be attributed directly to welding. Such conservation of wealth is sound economics, and the development of similar salvage projects should be encouraged.

Chapter VII—Arc Welded Steel Pleasure Cruisers

By Milo Bailey,
President, Bailey Steel Shipbuilding Co., Detroit, Mich.

The subject matter of this paper is the result of experience gained from the recent, actual, and successful construction of modern steel cruisers, designed for fabrication by the arc welded method.

The principles involved apply to all pleasure craft in the cruiser subdivision from 30 to 50 feet; and on up into the yacht class.

Fabrication by arc welding is not restricted to any particular type of hull design or construction. The subject matter herein, however, treats the type known as the "modified" vee-bottom cruiser. Its application to the traditional round bottom type is equally successful.

While this paper sets forth the advantages of arc welding over riveted construction, its main object is to show how the application of welding brings, for the first time in history, steel craft into even competition with production-built wooden cruisers.

It has long been conceded by naval architects, and builders of pleasure craft, that a hull built of steel under 50 feet could not equal the speed or have the strength comparable to one built of wood. Prior to fabrication by arc welding, the only means by which metals were joined was riveting, and the lightest shell plating having sufficient thickness to hold a rivet with the required factor of safety and a tightly caulked joint, was $\frac{3}{16}''$. The disproportional weight of such plating when used in a hull less than 50 feet upset its weight-displacement ratio, thus causing deeper immersion in the water and resulting in loss of speed. To this detriment is added the prohibitive cost of riveted construction, compared with current wood costs.

It is generally consided by builders, as well as the majority of cruiser owners, that if the weight-cost problem could be solved and brought down to a competitive basis with wood, a great demand would develop for steel craft because of their greater strength, safety, and low cost of maintenance. The superiority of steel construction over wood has been proven again and again, even when riveted—but when fabricated by arc welding the product becomes evermore one to be desired.

Comparative Strength of Wood and Steel Hulls.—At this point, it may be well to compare the strength of wooden hulls with steel, both riveted and welded, thus forming a basis upon which the full import of the advantages of arc-welded fabrication may be realized.

An analysis of the stiffness and torsional resistance of hulls, wood or steel, would be too involved and lengthy for this paper, but a simple comparison, that of tensile strength, may be easily made and readily understood from the illustrations in Fig. 1:

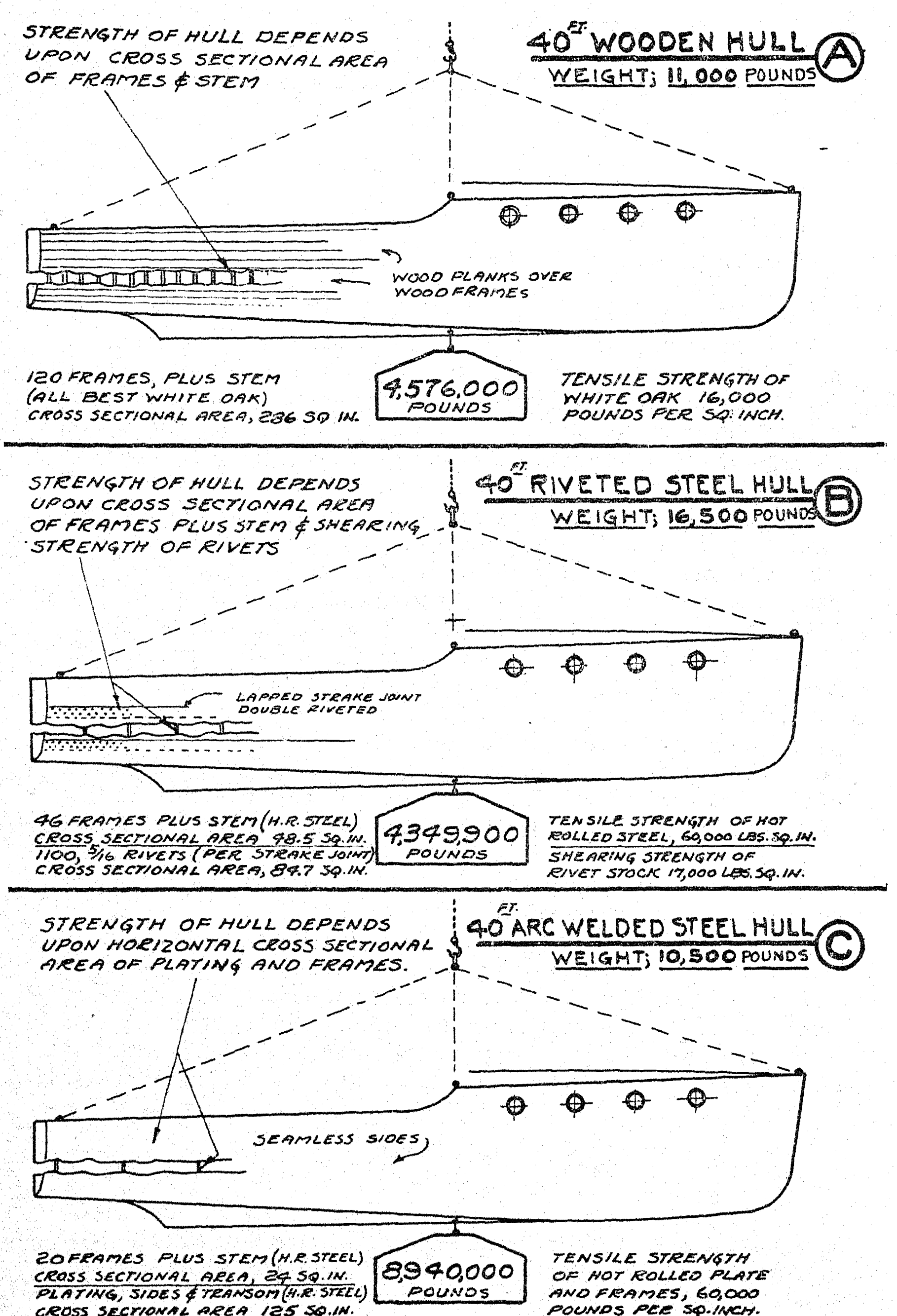

Fig. 1. Graphic analysis of stiffness and torsional resistance of hulls.

(A) A 40-foot wooden cruiser, currently produced by a recognized builder of a high-class product having extra staunch construction.

(B) A 40-foot steel cruiser of conventional riveted construction with $\frac{3}{16}''$ lapped shell plating in wide strakes from stem to stern, having two rows of $\frac{5}{16}''$ diameter rivets staggered and spaced 2″ on any given strake joint.

(C) A 40-foot modern steel arc welded cruiser having $\frac{1}{8}''$ thickness of shell plating, with plates full width from sheer to chine and chine to keel. The lengths vary from 12 feet down to 3 feet, with only one welded joint at the chine. This joint being stronger than the plating, the hull side is considered seamless.

Analysis of Comparison.—The surprise of this comparison lies, not in the fact that the wooden hull is stronger than the riveted steel hull, but in the excessive weight of shell plate necessary to adequately support riveted construction.

With the strength of hull (A) and (B) nearly even, but the weight ratio 2 to 3, it is clear then why the riveted hull could never approach the speed of a wooden hull, which eliminated it for all time as a serious competitor.

But the picture changes completely with the arc welded steel hull (C). Here we find the welded hull is actually lighter than wood, has greater speed because it is lighter—and is over 90% stronger!

Short statements all but they are facts!

If welded and riveted hulls were comparable in weight, there are many factors against riveted construction. First, the high cost; second, leaks at plate joints; third, rigidity of hull is only slightly better than wood.

To show how strength is increased by welding, we want to state that if hull (B) were welded, the strength would increase to almost three times that of the wooden hull (A)—a clear example of the inadequacy of riveted construction.

Although riveted steel hulls cost more and are heavier, we must nevertheless give them preference over wood; even though the strength seems low, they can stand greater impact of all kinds and harder stranding than wooden construction, and are much longer lived.

An adequately fastened riveted hull would require approximately 12,000 rivets. The punching, fitting, and registering of holes must be exact in so light a plate as $\frac{3}{16}''$, and the more fragile the construction the more costly the fabrication must be, as it entails a great amount of bracing and accurate forming.

The cost of welded construction compared with riveted shows the great savings in welding. Further, the close and expensive fitting-up of plates, punching, and registering of holes required for riveted construction are entirely eliminated—a major item of cost, as will be seen.

Cost of driving 12,000 rivets	$250.00
Cost of 12,000 rivets	10.00
Cost of laying 800 feet of weld with $\frac{3}{16}''$ electrode	80.00
Cost of $\frac{3}{16}''$ electrode (77 pounds)	6.93

From the above figures, welding costs slightly under 1/3 that of riveted construction, and slightly more than a half for material.

It may be estimated then that in addition to the savings of welding over riveting, that only one quarter of the cost of preparing plating for riveting is required in preparing plating for welded construction.

It is clear now that riveting has no place in fabrication where maximum strength is required and costs are to be reduced in conformity with modern manufacturing methods as we know them today. Therefore, the subject of riveting as applied to the construction of a modern steel cruiser will no longer be considered.

The remainder of this paper will treat only with the progressive construction of modern arc welded steel cruisers, and show how, by arc welding, steel cruisers can now more than compete with production-built wooden cruisers.

The question often arises, "If ships and large yachts have been built of steel for over half a century, why aren't small cruisers built of steel?"

The reasons, however, are not hard to find.

First: Prohibitive cost of riveted construction.

Second: Unwillingness on part of builders of wooden craft to depart from tradition or scrap investments in wood-working machinery.

Third: Most builders fundamentally are "wood minded".

Fourth: Those who have the zeal to develop or pioneer a new idea usually are the ones unable to finance the idea through to a successful conclusion.

Fifth: Fear of the "penalty of leadership".

Fundamental Requirements for Successful Fabrication of Arc-Welded Steel Craft.—First: It is necessary that the builder of arc welded steel have a thorough knowledge of wooden cruiser construction, as well as the intricacies of handling, forming, and welding steel; and be free from any prejudice for wood.

Second: He must be able to visualize the strength of a steel hull after it is welded, and carefully select the sizes of angles, channels, and bars going into the construction, accordingly. His temptation will be to "go heavy" in this selection at the outset, resulting in a heavier-than-necessary hull.

Third: The fabrication of all structure must be exact—closer than that of wood—because the builder cannot remove stock to "fair" up a contour or "sweep", except by grinding, and at great cost.

Fourth: A solid, accurate jig must be constructed to hold all framework rigid and in perfect alignment throughout the entire construction of the hull from laying the keel to completion of the final operations of shell plating sides and bottom.

Fifth: Inaccuracies must be corrected as construction progresses, otherwise, their multiplication develops into either a major problem of costly correction or poor appearance when finally finished.

Sixth: The entire procedure must be carefully analyzed and a progressive operation chart, (See Fig. 2), developed for sequence of operations, and rigidly adhered to.

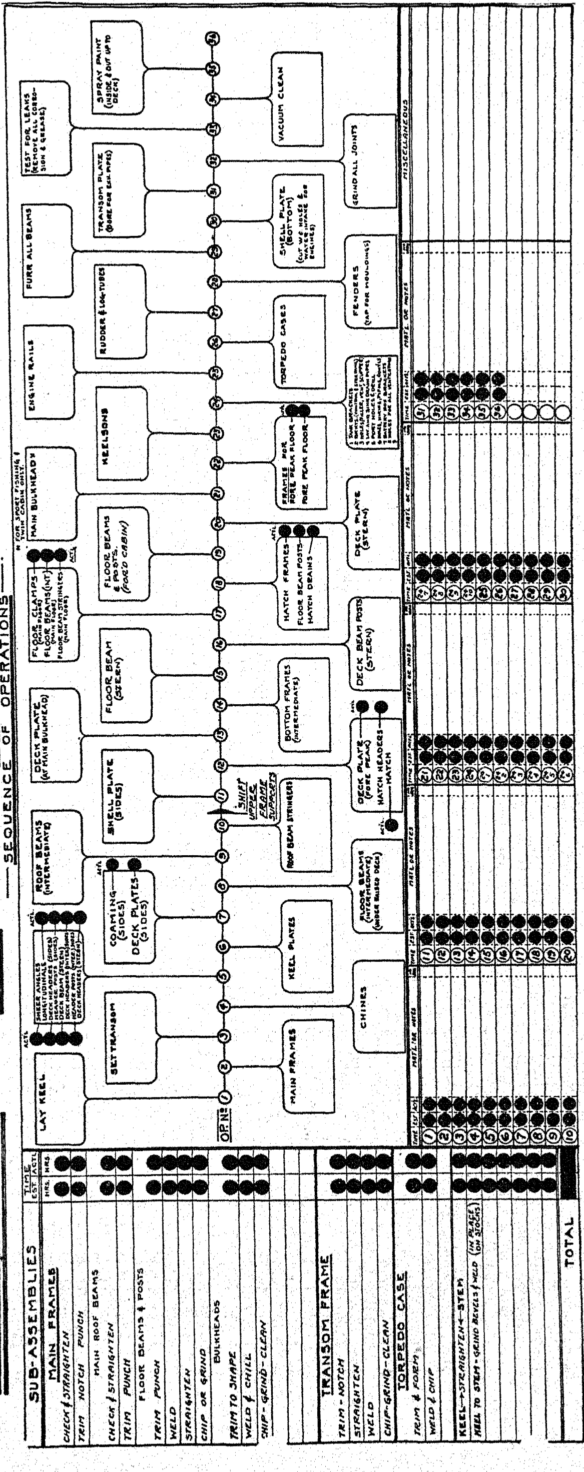

Fig. 2. Progressive operation chart in production of arc welded steel cruisers.

Seventh: Select a design of hull preferably developed for arc-welded construction.

Production Methods and Procedure.—The production methods hereinafter described were developed after several hulls were constructed and thoroughly tested, using different well known principles of hull framing, from which the one best suited for arc-welded fabrication was to be chosen for production, consistent with strength.

The problems, welding and structural, of each type of hull were solved, and methods used to surmount any difficulties were carefully noted and analyzed, with accrued improvements carried from hull to hull.

It finally developed that a modified "Isherwood" system of longitudinal support for the shell plating provided the greatest hull strength and lightness; and aided fabrication materially.

From this background of experience and mass of data the production chart, "sequence of operations," (See Fig. 2), was developed.

Close adherence to this sequence is absolutely necessary because it involves not only minimum of "labor" motion, but is in accordance with the welding procedure, learned from hard, expensive experience. It was found in many cases that operations and sequences had to be reversed to overcome distortion of plates or frames from heat of welding.

Operation sequence of the sub-assemblies such as keel, stem, and main frames does not appear in the chart, as these parts are fabricated outside on contract and delivered to the line in completed units. As no special problems are involved in making these sub-assemblies, only short description will be made covering their construction.

The most exacting and accurate operations, those which control the varying degrees of perfection of the completed hull, are tied up in operations 1 to 11.

Once safely past operation 11, only very lax supervision, poor workmanship, and bad welding can ruin the successful completion of a faultlessly fabricated hull.

Fabricating Jig.—Without the aid of an adequate jig, it is almost impossible to produce an arc welded steel cruiser that will pass the sharp inspection of a critical public. So many dismal failures have been made attempting to equal the hull-smoothness of wooden construction, that the boating public at large believes "it cannot be done"—and is usually skeptical until it sees. All criticism centers on the buckled shell plating caused from distortion in welding, and unevenness of line. There is no question of the strength of the hull or longevity, however.

When the plating is applied to frames, the frames must be immovable and rigid throughout this operation; otherwise the plating will pull the frames out of alignment and magnify the distortion, effecting smoothness of all lines that catch the eye. How distortion in shell plating is eliminated will be described at length further on.

The jig, (See Figs. 3, 4 and 5), consists of two heavy 6″ x 8″ timbers (skids) which form the base. These must be set perfectly level across and lengthwise, also parallel.

Upon the top surfaces are bolted the base beams, which are heavy steel channels, the aft faces of which must be spaced exactly the same as the hull frames—all perpendicular to the skids.

The "stocks" are now located on a centerline scribed across the tops of the base beams from end to end and bolted to the aft faces. The tops are notched to receive the keel and prevent lateral misalignment. Small angles are clamped to the faces and side of keel to hold keel in a vertical position, (See Fig. 3), until frames are welded in place.

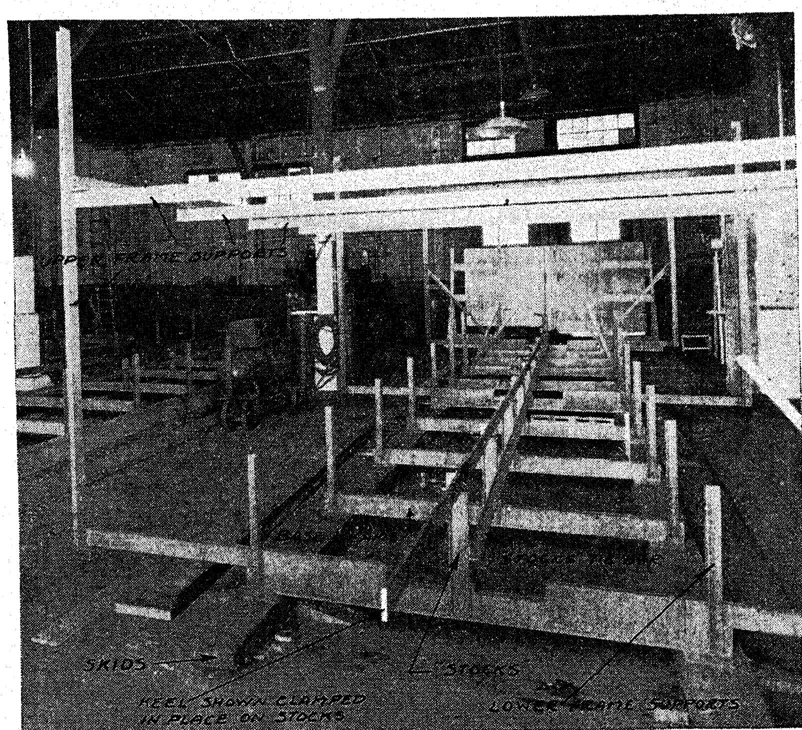

Fig. 3. Jig for fabricating steel cruiser—keel clamped in place.

A tie bar of angle iron is welded to the sides of the stocks for reinforcement from end to end. The lower frame supports are bolted near the ends of the base beams and are adjustable to any radial position when bolt is slacked. The upper frame supports are supported by six heavy vertical angles, the bases of which are welded to base beams extensions bolted to base beams. After operation No. 10, this whole upper structure is unbolted at the base beams and removed to the next jig to start another hull.

The aft faces of the upper frame supports are in perfect vertical and athwartship alignment with lower frame supports and stocks. Thus, when the hull frames are placed in position and forward faces clamped to supports, they are in perfect alignment all ways, square and plumb.

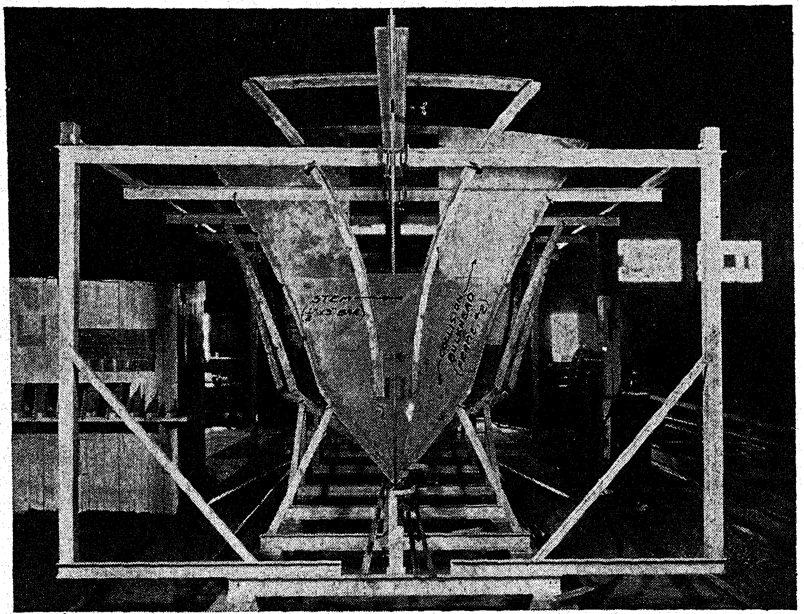

Fig. 4. Frames clamped in place to upper and lower supports.

Here it may be stated that the accuracy of the entire jig is held to a plus or minus limit of $\frac{3}{64}''$. This is easily accomplished when a structure such as this is welded.

The accompanying illustrations clearly show the entire jig construc-

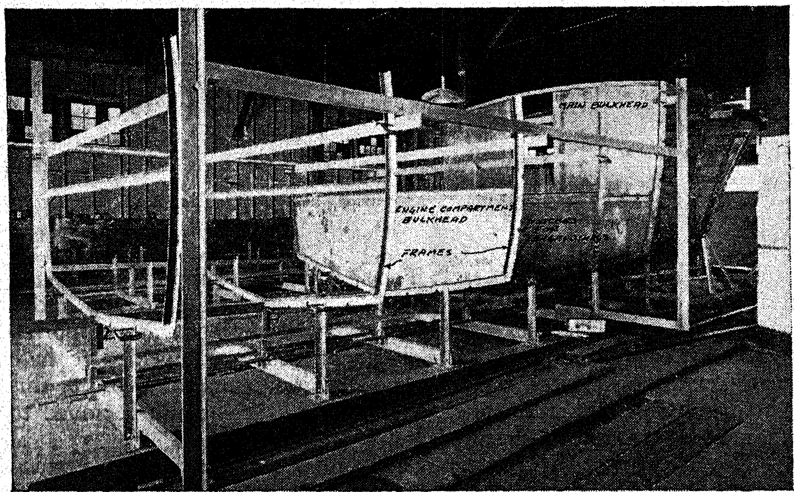

Fig. 5. Quartering view of jig, showing aft frames, main and engine compartment bulkheads in place.

tion and progressive assembly of the hull. A glance through the "sequence of operations" chart will amplify the procedure.

As the work progresses and the hull increases in weight, the base beams are checked frequently for levelness. This is to assure against twist of jig in case the footing under the skids settles during construction. If the skids are laid on a concrete base this will not occur.

Fabrication.—To clarify the illustrations, notes will be used.

Fig. 6, Section I, shows the detailed construction of an aft main frame. This assembly is made up of two side and bottom members, rolled to a pre-determined arc, cut to template, and welded together in a flat steel jig.

The points at deck plate, chine, and keel are located to exact position by stops on the jig, holding the accuracy to $\frac{1}{32}''$. After locating these parts, they are heavily clamped with thin copper strips under the mitered joints and joint at keel. This copper plate prevents welding frame joints to the jig. It also dissipates heat quickly.

To facilitate welding speed, these joints are welded only on one side, with the welding mostly down-hand and at a very convenient position for the operator. After welding is completed and floor beams are welded in place, the frame is left to cool completely before removing from jig, allowing the stresses to equalize, eliminating distortion.

The next operation is mechanical, consisting of notching out for longitudinals, chines, keel, and keel plates, all of which is done on a punch press, and accomplished in a few minutes.

The frame is now placed back on the welding jig to further check for distortion. Passing inspection, it is ready to be set in position on keel and clamped to the fabricating jig upper and lower frame supports. From this point the sequence of operations is followed, and Section I of Fig. 6 shows all members in position in cross section up to the shell plating operation No. 11.

Section II of Fig. 6 is a cross section through the hull midway between aft main frames, showing how the longitudinals are braced between frames to eliminate any "flatting" when shell plating is welded in place, and adding considerable strength to the whole side structure.

It becomes apparent from an analysis of the design of frames and method of re-enforcing that tremendous strength is built into the hull sides, actually developing into a deep girder section averaging 5½ feet bottom to top the full length of the vessel and accomplished with the use of relatively light sections of metal in all component parts. Such structure, held together by arc welding becomes tremendously rigid. Hull strains, resulting from violent action in the water, do not localize in any particular section, but are distributed over great areas.

Contrast this with wooden hulls where all strains localize at the fastenings, which become loose allowing planking and framing to weave and open up. This is one reason why wooden hulls have only half the life of steel.

Shell Plating.—Shell plating can be the stumbling-block in successful construction of all light-weight welded craft.

Careful analysis of failures indicate the following reasons: (1) steel

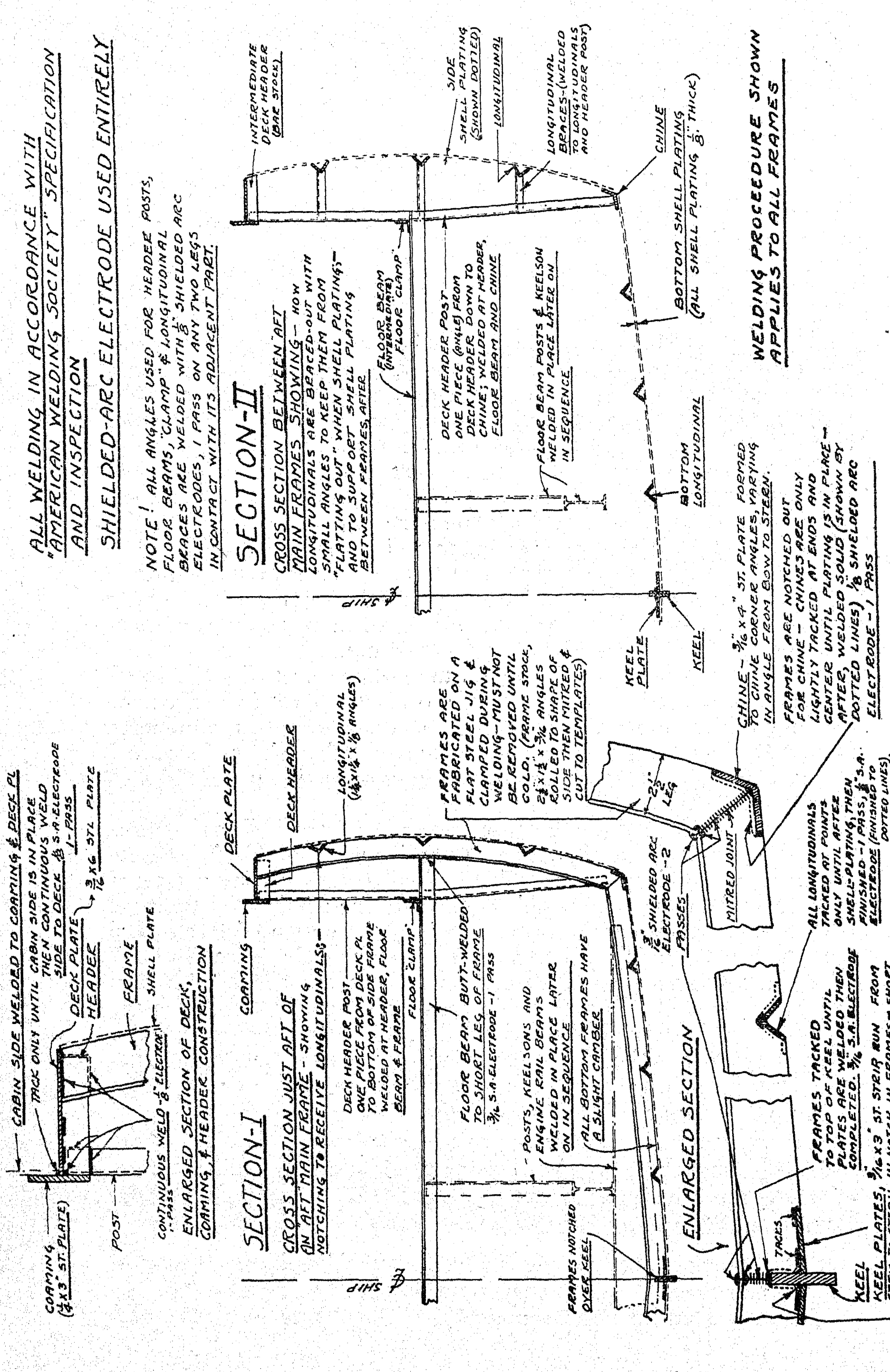

Fig. 6. Details of arc welded cruiser construction.

sheets have hard and soft areas, locked-up rolling stresses, and waves; (2) forcing sheets to conform to frame curves sets up stresses which are released by welding heat into uneven "breaks" and irregular surfaces; (3) framing is weak and poorly supported; (4) frames or longitudinals are not "fair". ("Fair" is the evenness of continuous curves from bow to stern, or sheer to keel at any section of the hull surface); (5) welding heat is poorly controlled, and size and quality of electrode used is incorrect; (6) welding speed is excessive and time allowance for cooling is inadequate; (7) operator lacks good welding sense and good judgment of heat adjustment; (8) means of holding plating to frames during welding operation is inadequate.

Assuming all the adverse conditions above have been overcome, the procedure for successful shell plating is illustrated and described as follows:

Fig. 7 is an outboard profile of hull indicating sizes of sheets used, welding procedure, and details.

The first operation in plating is to make templates of light wooden strips nailed and glued together, the outside edges of which are even with the deck plate line, forward and after edge of plate, (whatever length decided upon), and the chine corner, or lower edge. This gives the developed shape of the plate, and when flattened out on the blank sheet the edges become the line to which the sheet is trimmed. This trimming is done by a new type of portable electric shear which trims to any contour at the rate of 6 feet per minute with a maximum capacity of 1/8″ plate.

All plates are now rolled to the approximate curve of the frames they cover. Preliminary rolling, no matter how slight, is necessary to smooth plating, because the stresses then have assumed the characteristic of the frame curve and remain static with no tendency to "release" in other direction when heat of welding extends its area and upsets the molecular structure of the steel.

The plates are now "hung" from the tops at the deck plate edge by "C" clamps—then shaped "strong backs", (angles bent to a slightly greater radius than the frame contour), are clamped over the plating and held at tops also by "C" clamps. The "strong backs", spaced about a foot apart, are brought down tightly over the plates, thus bringing plates into contact with the frames and longitudinals tightly, then they are clamped to the chine.

By hanging plates from tops and "ironing out" toward the chines, advantage is taken of gravity to hold the plate close, (plates weigh from 200 to 350 pounds each) and overcome friction from plates creeping on frames or longitudinals.

Plates are now ready for welding to structure and, progressively as noted in Fig. 7.

Water Cooling.—During the entire welding operation, that of welding plate to longitudinals and frames, (but not deck plate or chine), the plates are cooled with a fine spray of water near the vicinity of the weld, restricting expansion and shrinkage to a small area around the weld, and stopping heat penetration before it can cause distortion of plates in the unsupported areas. Tests have been made chilling the weld

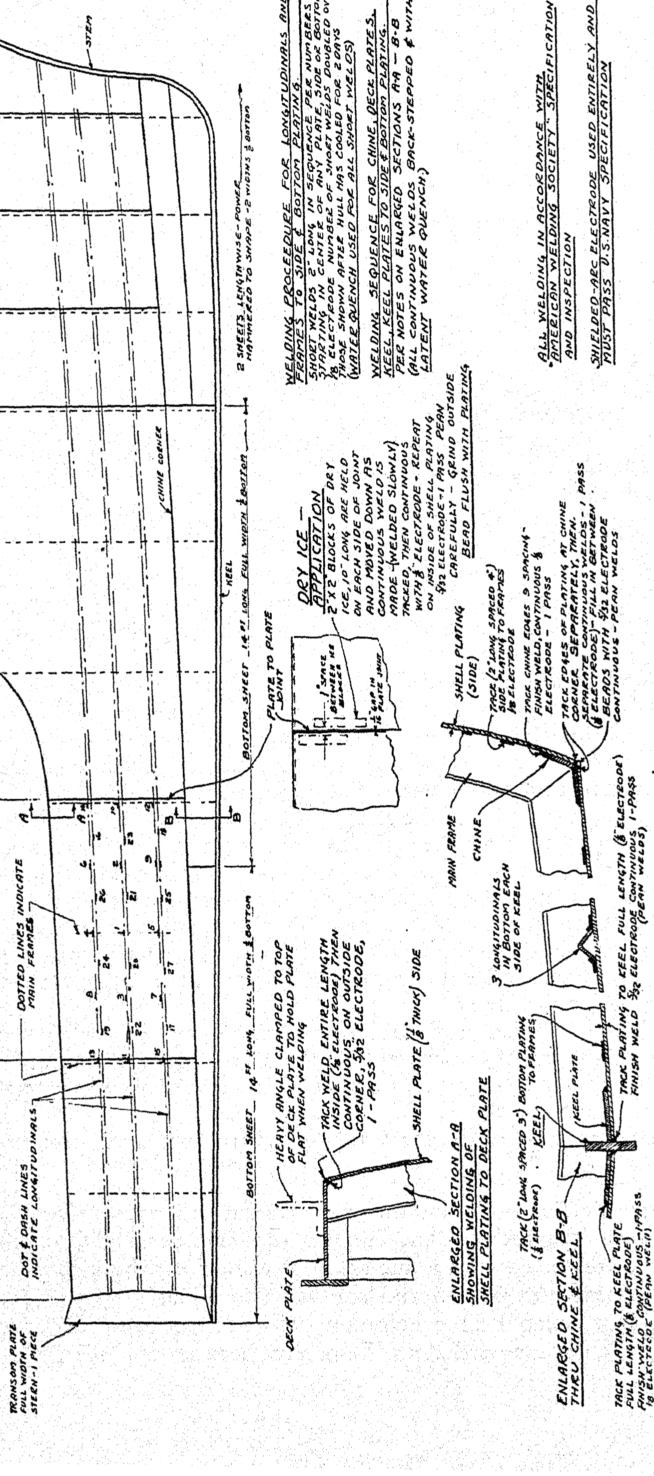

Fig. 7. Outboard profile of arc welded steel hull.

while still cherry red with no tendency to crystallize or reduce strength of either the weld or plate. Water cooling, therefore, is safe and aids materially in eliminating buckles. The continuous welds at chines and deck plates are cooled more slowly as the thickness of metals here varies and a quick quench causes plating to shrink faster than the chine or deck plate.

Welding the plate-to-plate joints has always been a source of trouble. Various gaps were tried with varying degrees of success. The particular difficulty lies in the expansion of the two edges toward one another to the extent of causing an in-or-out buckle, full width of the shell plate. To prevent this, dry ice was used.

The theory of application of the dry ice was: if the heat of the weld on the edge of each plate at the joint could be restricted to a very narrow margin on each side of the weld then the amount of expansion of each plate toward the other would be reduced to within the limits of the narrowness of the margin; thus reducing the in-and-out buckle to a minimum. Placing cakes of dry ice on both sides of the weld with the closest clearance possible, consistent with the operator's skill, restricted this area down to within one inch total and solved the problem.

The dry ice absorbed the heat so fast there was no spreading of heat beyond the margin; therefore, minimum of expansion. The application of dry ice to the welding of bulkheads to frames was used with great success, as all sheets were perfectly flat when finished.

Bottom Plating.—Bottom plating does not present the difficulties encountered in side plating, as it has very slight convexity and practically no forming. The exception is at the bow end where it is power-hammered to templates. These plates are developed and trimmed the same as the side plates, and held in position against the bottom frames and longitudinals by several straight heavy angle irons running fore and aft. The welding procedure is identical with the sides.

Testing for Watertightness.—After all shell plating, sides and bottom, also transom plate, have been welded, all welds are smoothed up by grinding. Carbon-tetrachloride is then flowed on all joints to test for leaks. Any found are promptly closed by welding, re-ground and tested again. Much credit can be given this method of testing, because carbon-tetrachloride can penetrate the most minute opening. Suffice to say, no hull so far has ever leaked a drop that has passed this test!

The main problems encountered in fabricating arc welded steel cruiser hulls have been set forth and the method of their solution, from practical experience, described. Therefore, as there are no remaining problems involved in the finishing of the cruiser, description will here be concluded.

Comparative Cost of Wooden and Arc Welded Steel Cruisers.—Costs of welded steel cruisers compared with wooden cruisers are about equal when a low quantity production in steel exists, but in quantities equaling large wooden production, the cost of welded steel cruisers will be less by 14%. (The writer manufactured wooden cruisers for several

years before producing in steel and substantiating data on costs are on file).

Increased Service Life, Efficiency, General Economy, and Social Advantage Provided to Mankind Through the Use of a Modern Arc-Welded Steel Cruiser.—A welded steel hull is no heavier than a soundly constructed wooden hull of the same size, even when the wooden hull is new. And, of course, a steel hull does not soak up water and become heavier with age as a wooden hull does. Consequently, a steel boat remains the same weight throughout its entire life.

The normal life of a steel hull is twice that of a wooden hull for it is not subject to the rot nor to attack from marine borers. It never requires caulking or replacing of planks, and, of course is far stronger.

A welded steel hull is more easily repaired than a wooden one. It requires only cold bumping, and in case of a through fracture, welding. If planks are smashed in a wooden hull, it becomes a long drawn-out expensive operation. For every experienced boat builder who knows how to replace a plank there are a thousand metal workers. Most any small town garage has a metal man but you won't find a planker in every out-of-the-way place.

Today, new corrosion resisting steel alloys, rust preventatives, new finishes and new methods of steel treatment produce corrosion-proof hulls. New insulation and air conditioning principles eliminate sweating, or condensation, on the inside of a hull. In a properly constructed modern steel cruiser, the bilges are so dry they are actually dusty.

Compare this with the wooden cruiser which must be caulked, have rotten or broken planks replaced, have its fastenings tightened, and must have constantly pumped out the slimy water of an always submerged and more or less leaky bilge.

A cruiser built of steel is safer, cooler, always dry inside, retains its shape, can be frozen in without harm, and is more sanitary.

When you step into a steel cruiser, you immediately sense a feeling of greater stability. Subconsciously, you know that watertightness is assured because there are no seams to leak or open up in a blow. You notice "liner" technique of construction—steel bulkheads that can't fail, engine compartment welded to air tightness from the main portion of the hull, (an item assuring fire-proofness), and most important of all, you notice that here is a ship which, because of its natural strength of construction, can stand a battering that no wooden one could take.

Finally, such a boat costs no more to buy in the first place than a well-built wooden boat, and the lower upkeep cost and longer life make it far less expensive to own in the long run.

Summed up, the advantages of steel construction are: all-welded steel hull and superstructure—no leaks; maintenance cost is 1/4 that of wood; cabin sides cannot crack or open up; hull can be frozen in without harm; complete insulation against heat, noise, and vibration; cooler in the tropics; immune to marine borers (teredo); quieter and smoother; dusty-dry, odorless bilges; no wet rot or dry rot—no caulking; built for use in any waters; engines in stern, enclosed in fire proof steel compartment.

Chapter VIII—Arc Welded Steel Construction of Auxiliary Cutter Yacht

By J. MURRAY WATTS,
Naval architect, Philadelphia, Pa.

The welded steel auxiliary cutter yacht, "Southern Seas," (See Fig. 1), is interesting for two reasons:

(1) It is one of the first small seagoing welded sailing yachts ever built. By this is meant a keel boat of curved moulded sections, not a V-bottom, or flat bottom boat.

While the author has frequently designed large welded vessels, these are becoming more and more standardized. A sailing yacht under 36 feet calls for a new technique to make her light enough to compete with existing yachts.

(2) This boat is being constructed* from my designs by Hoskins & Co. Ltd. of Perth, Australia, for Mr. I. H. Ineson of Perth.

As this yacht is building by an Australian firm, the American Welding Society Symbols are not used. The location of the welds are indicated, but the contract called for the foreman welder to conform with the shop practice of Hoskins & Co., Ltd.

The costs of both labor and material are higher in Australia than in America.

Proportionate Cost Saving in Percentage.—From building records, the saving in cost is 3 per cent over riveted construction done in the same yard, and 12 per cent in weight. Also the time of construction was reduced about 15 per cent.

The plating is $\frac{3}{16}''$. This required a welding current of 190-200 amperes, 30 to 35 volts, using $\frac{1}{4}''$ coated electrode. A total of 16 pounds were used per foot of weld. Length of welding for plating seams was 1350 feet. Length of welding for framing was 1050 feet.

Actual Welding Costs

$\frac{3}{16}''$ plating seams $0.15 per foot, 20 feet per hour,=$3.00 per hour
Deck and hull framing $0.10 per foot, 30 feet per hour,=$3.00 per hour

Actually welding labor was 6 shillings per hour, or about $1.40 This allows $1.60 for coated electrodes, current, setting up time, rent, overhead, etc.

The costs came to . . . 1350 feet of plating @ 15c	$202.50
1050 feet of framing @ 10c	105.00
Heavy welding on ¾ inch keel and stern plate	18.30
Total welding costs	$325.80

Riveting costs on same job were $340, or a saving of approximately 3%.

*At time of writing paper.

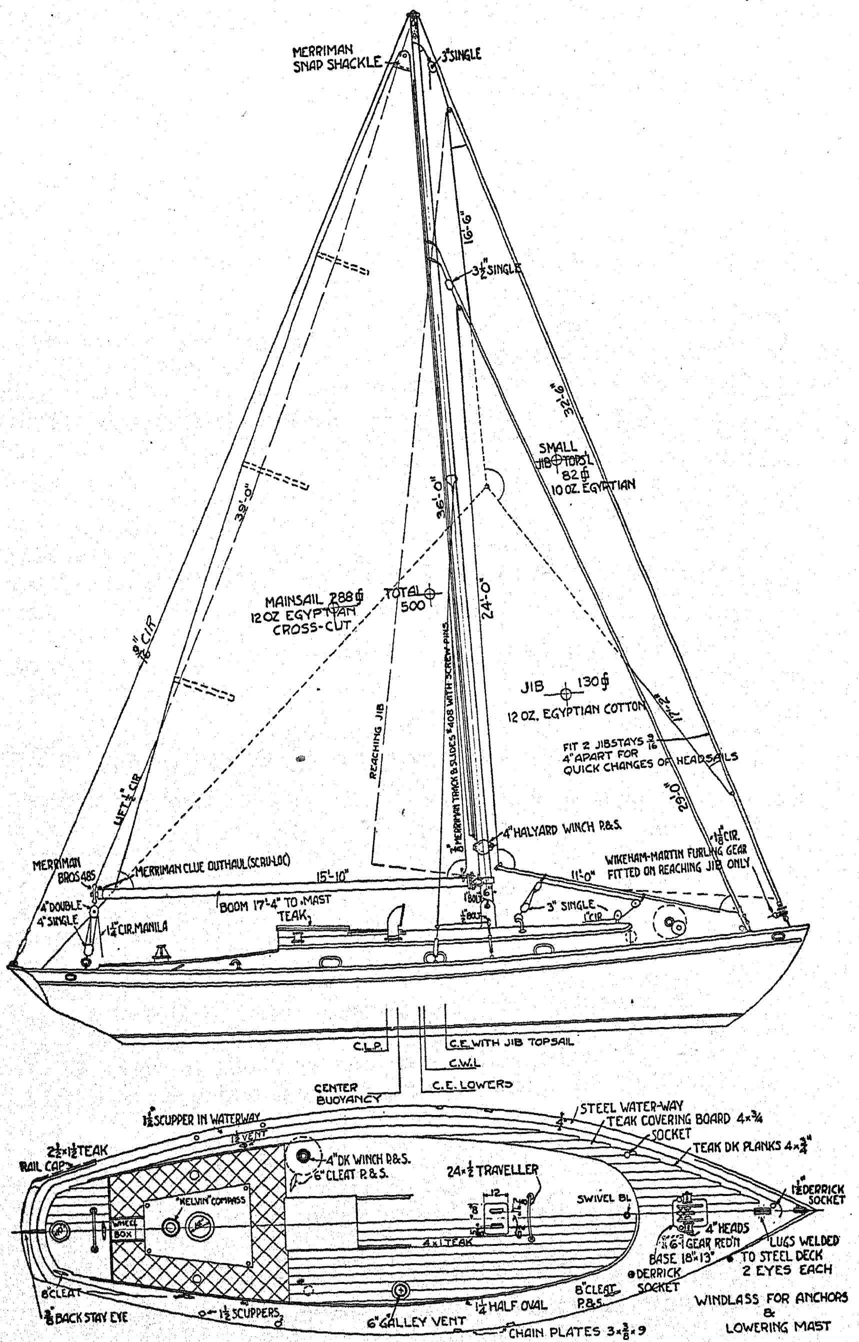

Fig. 1. Deck, profile and sail plans of arc welded auxiliary cutter, "Southern Seas."

Gross Savings.—The gross savings accuring to industry by the general adoption of the design described are difficult to depict. A pleasure watercraft, such as a sailing yacht, varies in almost every design order. If a large number were turned out as stock boats, the gross savings might run to 10 per cent.

Increased Service Life, Efficiency, General Economy, and Social Advantage.—These show up well on this design, compared to existing sail boats of this size, which are 99 per cent wooden and 1 per cent steel riveted.

The welded hull, as proved on larger boats, shows increased service life, through absence of leakage. On the few yachts and commercial craft the author has built under 36 feet in length, experience shows that these welded hulls do not leak, even when strained in a heavy sea, which might start the rivets in the older riveted steel construction, and start the seams on wooden hulls.

In general, a wooden hull weighs less before launching, but in practice she soaks up water enough in a few weeks to lose this advantage. Moreover, it is very rare to inspect her bilge and find no water in it.

With the method of sand blasting and spraying the hull inside and out with molten zinc, used in the present design, the service life is increased to 50 years, about double the life of an ordinary boat.

This method also does away with the necessity and cost of frequent painting as the heavy zinc lasts a lifetime.

The chief social advantage is safety for the passengers. Welded plating has been known to crumple up like a concertina in a collision, without starting a seam.

Compared to the vast majority of wooden boats, the welded steel craft is free from the danger of destruction by fire.

The danger of a punctured hull can be greatly reduced by the ease and cheapness of fitting her with absolutely water-tight bulkheads.

On a sail boat the tremendous advantage of having no free water in her bilges is the greatest factor of safety of all.

It only takes 35 cubic feet of water to weigh a ton, and this weight rolls down to leeward in a storm and reduces the stability of the hull frequently to the danger point, and a capsize results.

Other safety features are mentioned in the following descriptive pages, which with the drawings make clear the method of erection.

Dimensions of the cutter "Southern Seas."

Length overall	35′ 9″
Length on deck	35′ 0″
Length water line	27′ 0″
Beam	10′ 0″
Draft	5′ 0″

Method of Erection.—The lines, (See Fig. 2), are laid down on the mould-loft full size, from the table of offsets, the stations marked in on the body plan. Next, each frame and bulkhead is marked at the

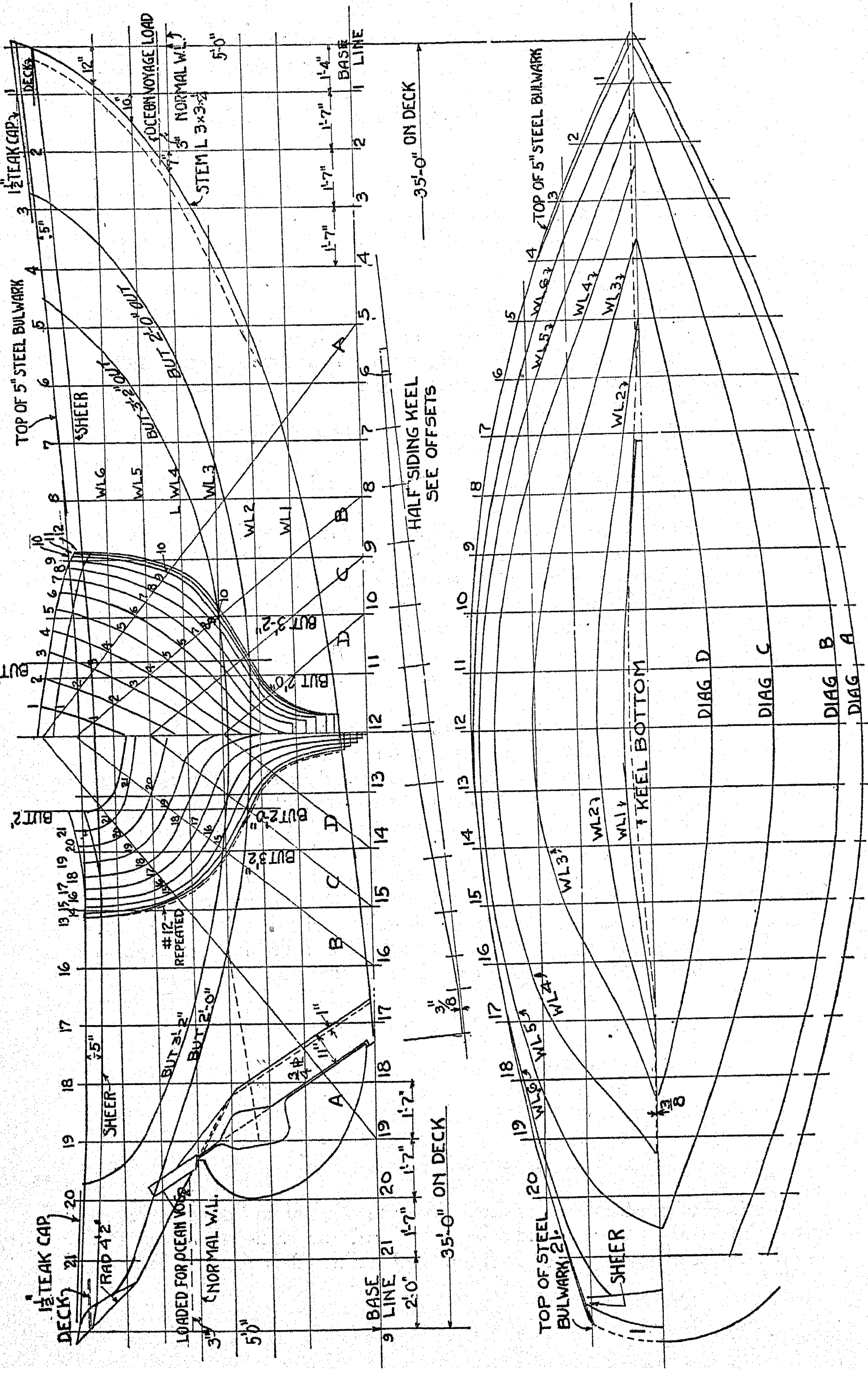

Fig. 2. Lines of 35-foot 9-inch arc welded cutter "Southern Seas."

given spacing. The stem, keel assembly, stern-frame and transom-stern are marked, cut out of steel of given thickness, and this whole "backbone" set up on keel-blocks, and shored plumb.

The frames and bulkheads are then shored plumb at given 19" spacing and welded to keel. The heads of frames are welded to brackets for deck-beams; frames in way of cockpit welded to cockpit-beams also.

The plates forming the sheer-strake are now welded to the bulkheads and frames, and to stem and to the stern transom.

The stringer-plate, (namely, the outer deck plate), is now welded to the top of the deck-beams and brackets.

This stiffens the structure so that the rest of the shell plating may be now started. First, the garboard strakes are welded inside and out. At the stern they are welded to the stern-frame plate. All shell plating welded W.T. to bulkheads, and intermittent to frames and brackets.

Next, to keel—at the after end where it is narrow—the opposite garboard plates should be welded at the same time, otherwise the keel may be distorted.

The next two strakes are now welded to the floors, frames and bulkheads. The balance of the shell plating may next be welded in place as convenient. It is good practice on small yachts and vessels to use plate 24" wide on flat sections, and 12" wide where there is much curvature. Longitudinal seams are welded against a seam-strap. Vertical butt seams are welded against a butt-strap.

Seam straps may be intercostal, or they may run continuous from bow to stern by notching in the frames and deck-beams 1¾"x$\frac{3}{16}$" deep.

It is much easier to fair up the plating if these straps are welded continuous.

Steel Structural Members.—All sizes to conform with specifications on sections, (See Fig. 3) Keel bar is ¾"x12". Stern frame plate ¾" is welded to keel and to floor frames. Stem angle 3"x3"x$\frac{5}{16}$" is welded to keel.

Transverse framing and stiffeners are ¼" flat bars. Angles are only used where sheathing is required.

Sheathing, either plywood or sheet aluminum, is fastened to angle flanges with round-head machine screws. Same construction is used for deck-house.

Floor frames are flanged only to support plank flooring and engine bearers.

Shaft tube consists of X-heavy 3" pipe welded to keel assembly, fitted with stuffing-box at inner end, and rubber bearing and scoop at outer end.

Rudder port is 1¼" iron pipe, welded to the 2 parts of the stern frame and fitted with stuffing-box at upper end.

Engine beds are built with ¼" plate members, with heavy angle fitted to support the type of engine furnished by the owner.

Bulkheads are built of ⅛" plate, except the lowest strake, which is $\frac{3}{16}$" same as floor-frames. All are stiffened and edges of doors reinforced.

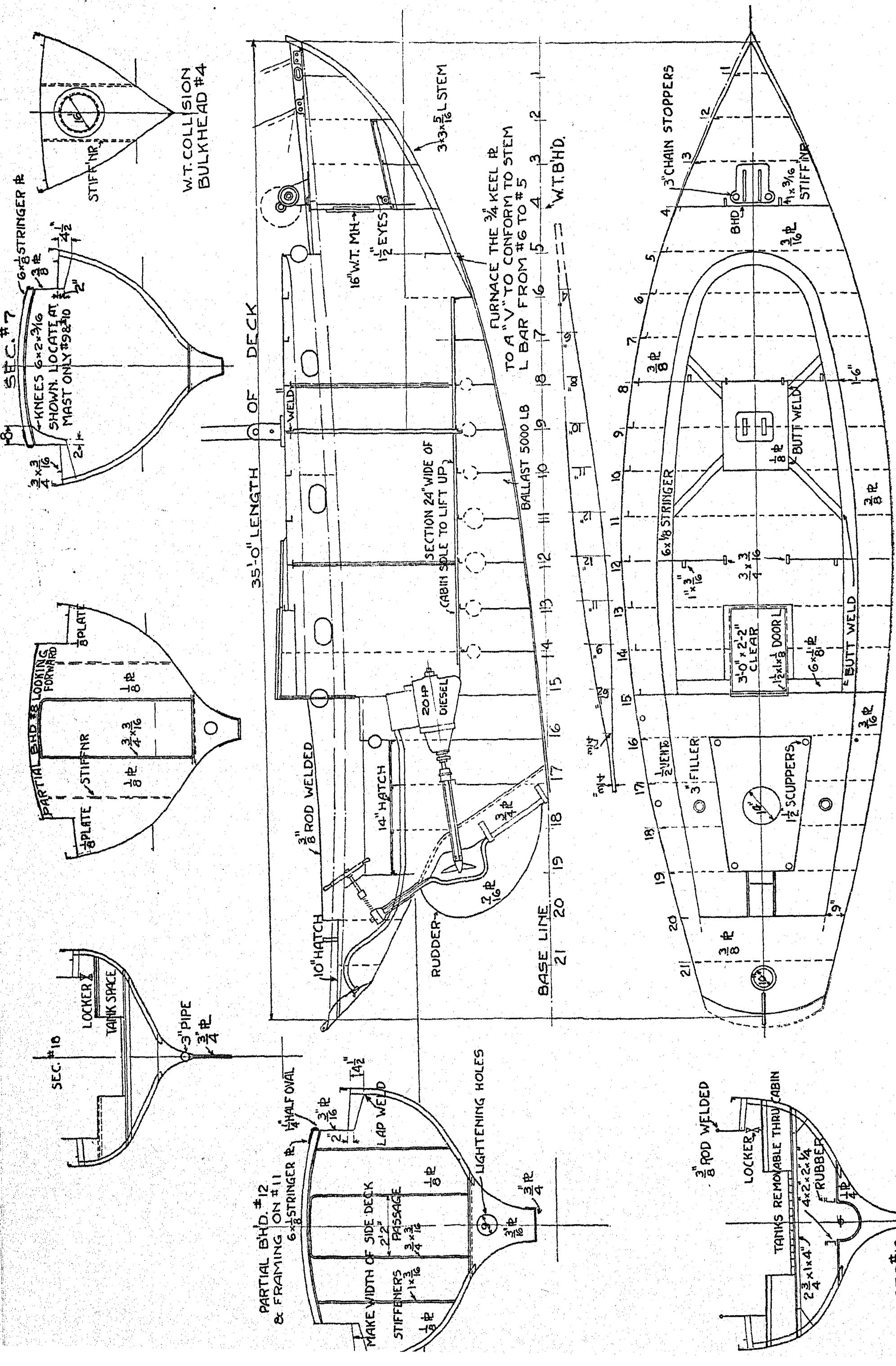

Fig. 3. Sections and specifications of arc welded cutter.

The frames are cut short and welded to floor plates, and to bracket plates. Frames are spaced 19″, and are angles from Nos. 3 to 14, elsewhere 1/4″ bars. Frames at the bow may be canted. Frames at the stern-transom are 1/4″ bars spaced the same 19″.

Plating is flush with butt-straps of 1 3/4″x3/16″.

Angles, where used for frames, are 2″x1″x1/4″; for cabin beams 2″x1″x1/4″; for stiffeners 1″x1″x3/16″; and for rail 2″x1″x1/8″.

Welding in General.—Current employed should be low voltage, D. C.

3/4″ plates, 350 amps. and 40 volts for 3/4″ keel and stern frame. 3/16″ plates, 190-200 amps. and 30-35 volts. 1/8″ plates, 100 amps. and 40 volts.

Steel plates should have a carbon content of not over .017. Welding rod should have a carbon content of not over .025. Hull plating is continuously welded to the keel, keelsons, stem, stern-frame, transom, and fenders, and to all bulkheads.

Intermittent welding connects hull plating to frames and floor-frames and deck plating to deck-beams. Continuous welding connects deck plating to all coamings.

Hull plates are flanged and welded inside and out to the stern frame. Bulkhead and deck-house stiffeners are intermittent welded to plates. Work should be arranged to have welding dome from above where possible.

Where working space is constructed, plug-welds may be used. Holes must be 2 1/4 times the thickness of the plate.

If equipment is available, shot-welding may be used on very light plating.

All welds on the outside and where visible in the cabins shall be ground down to a smooth finish. Use reverse polarity with shielded arc. Use motor generator of variable voltage type, so as to shorten up the heavy wiring, using No. 2 flexible multi-wire cable.

Chapter IX—Improved Methods of Building Small Pleasure Craft by Use of Arc Welded Steel

By Elliott Gardner,
Naval architect, Hyde Boat Yard, Scotia, N. Y.

This paper deals, not with the building of any one boat, but with a perfected system and type of construction which may be successfully used in the design and building of any type of pleasure boat from 16 to 80 feet. Fig. 1 shows a number of pleasure boats of arc welded design and construction.

Arc welded steel boats will not only be lower in first cost but they will be infinitely less expensive to maintain. Steel boats built by latest improved methods show the lowest maintenance costs ever recorded in the pleasure boat business.

The new steel boats will be lighter than the water soaked wooden hulls with their ever-present bilge water slopping around under the floor. The steel boats will not leak. Like those we have built, their inside bottom surfaces will be so clean and dry that the inside of their hulls can actually be painted while afloat. Because these boats are so light and dry, they will naturally be faster, safer, cleaner, more seaworthy, and have greater carrying capacity. Unlike the leaky wooden boat, they can be kept afloat without watching or pumping for long periods of time.

Among the advantages discovered by welded steel boat pioneers was unusual strength. Not merely the strength that was calculated in the original design, but additional strength from every angle that exceeded all expectations and went far beyond the fondest hopes of the most exacting owners and designers. Today, welded steel boats are gaining attention by such spectacular stunts as crashing at 18 miles an hour onto a concrete sea wall with such force that 2/3 of the boat's length is run completely out of water and up the steps of the sea wall. This has been done repeatedly without serious damage to the boat. We have dropped a 21-ft. by 7-ft. boat ten feet from a crane hook to concrete pavement without serious injury. We have run the same boat at 18 miles an hour through fresh hard ice 1-inch thick and subjected the boat to many other extraordinary tests which would completely wreck any wooden boat regardless of its construction. Because of this infinitely superior strength, with which the strongest wooden boat ever built cannot even be compared, we have attained a still greater measure of safety and seaworthiness never before possible. Because of this greater strength of welded steel, we can attain still lower limits of light-weight construction for boats of higher speed.

It is easy to see how a welded steel hull weighing 500 pounds less than a wooden boat of the same size and shape, will have a definite advantage in speed, economy, and carrying capacity which cannot, by any possible means, be made up in any way by the wooden boat.

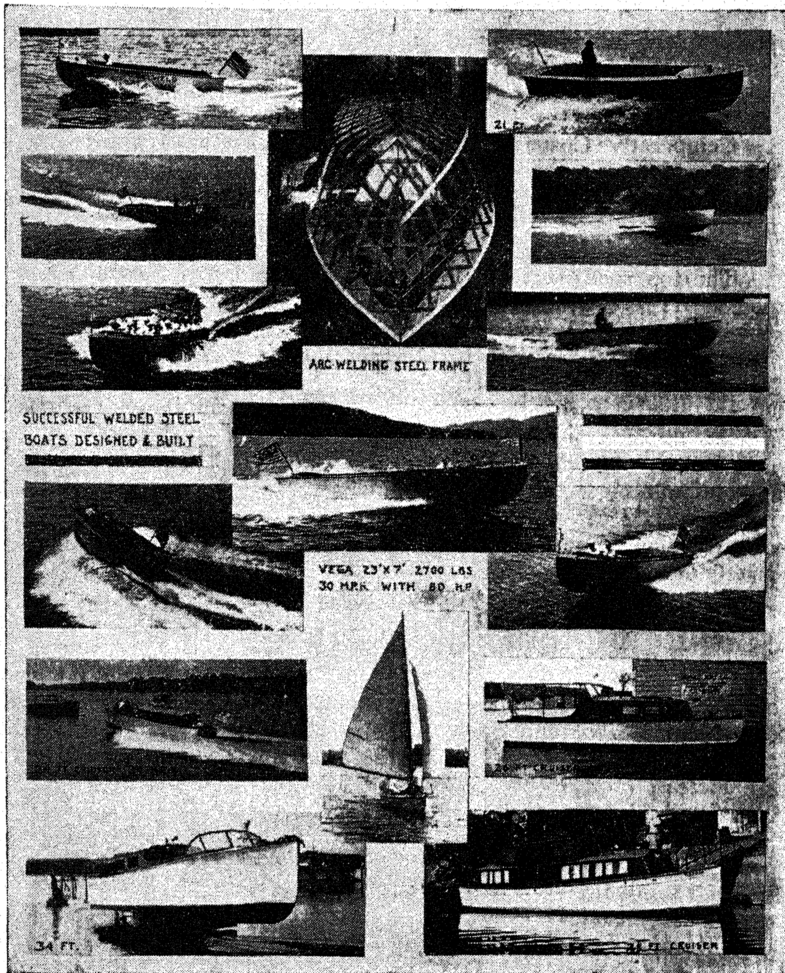

Fig. 1. Pleasure boats of arc welded steel design and construction.

As further proof of the incomparable superiority of the welded steel hull over the wooden hull, the writer has caused to be constructed from his design and under his personal supervision, three boats whose design was identically the same in every detail except that two of the boats were built of welded steel and one boat was built of wood in the best approved manner by a reliable boat builder. For further comparison of values, a fourth boat of wood of reasonably similar design by the author and powered with a larger motor was also used as an example. In order that this test might be of greatest possible value, the size and type of boat chosen was a 21-foot by 7-foot Vee-bottom runabout which is typical of the most common and popular type of pleasure boat on the market today. This size represents a fair average of the majority of practical pleasure boats. The cost figures are of boat complete with

power plant, only without reference to expensive fittings and equipment which have no bearing on the question of comparative cost and were left out on all tests to avoid possible unfairness in weights.

Comparative Cost and Efficiency—Welded Steel vs. Wood.—Figures show us that the wooden boat, which has identically the same bottom lines as the steel boat, with the advantage of being 2 feet shorter and having an additional 5 horsepower, did not at any time equal the performance of the steel boat.

The top speed was 1-mile less notwithstanding the extra 5 horsepower. The speed, after soaking up, was 3 miles less, showing a loss of 10 per cent. The carrying capacity is more than 20 per cent less. The increased cost of operation is 20 per cent more. The cost of replacing lost speed with more power would add 20 per cent to first cost and 20 per cent to fuel costs. The cost of storage, refinishing, and repairs is over 100 per cent more. The building cost of the wooden hull, without motor, was $200 more than the arc welded hull. Both boats were custom-built by expert workmen under the same working conditions, from the same design and under supervision of the same designer, (this cost was figured on actual labor and material only in order to approximately equal the cost of quantity production). The steel boat was built to sell for $1095 complete while the wooden boat, with its larger power plant, was priced at $1475. It was estimated that in quantity production these boats could be sold at these prices with a net profit to the builder of $150 per boat and an additional allowance of $200 for selling expenses. The builder of the wooden boat found by careful check of every hour's labor and every cent's worth of material that he could not get his price down to the steel boat price under any circumstances. An increase of $200 over the steel boat price allowed him only good wages and 15% overhead for his small shop.

Comparative Length of Useful Life—Welded Steel vs. Wood.—In addition to all the aforementioned points of superiority in favor of the welded steel boat we have one more overwhelming advantage. The long life of a boat is a point well worth considering.

The best of wooden boats are subject to decay in certain ill-ventilated and unpaintable spots in spite of the best of care. The well designed welded steel boat will have no spots which cannot be ventilated and painted, hence the decay or rust possibility may be practically eliminated except in cases where gross negligence permits it. The life of a well-built wooden boat is almost entirely dependent upon the care it receives. 40 to 60 years is not uncommon among the well-built boats of the past, whereas, 4 to 6 years is a better estimate of the low-price boats now being sold.

In an extensive statistical study of what becomes of old boats, we find that nearly all well-built boats end their careers either directly or indirectly as the result of accidental damage. A great percentage of the present low cost variety are abandoned after a very short life because they are unfit for use and leak so badly as to be beyond repair. Usually one or two minor accidents are sufficient to terminate the career of the

latter variety while the older well-built variety often survive many major accidents except that of fire.

Unfortunately, we have no welded steel boats which are 30 years of age with which to make comparisons. We do have, however, a great number of the pressed-steel boats with riveted and soldered seams which were manufactured about 20 to 30 years ago. Searching the history of a large number of these boats, we find that they have survived all the ravages of time and the natural succession of accidents to which amateur yachtsmen subject their boats. We find many of these boats still in service after many accidents which no wooden boat could possibly survive. The weak point of these older steel boats was the riveted seams and the wood-re-enforcing members. Our new welded steel boats have none of these weak points and we have permitted our experimental boat to be subjected to 4 tests and 4 accidents, any one of which would have completely wrecked any wooden boat. The boat has withstood all these tests in such a manner as to indicate that the useful life of our welded steel boats could be, conservatively estimated, ten times that of the low-cost wood boats of today and 2 to 3 times the average length of life of the high cost boats of the past.

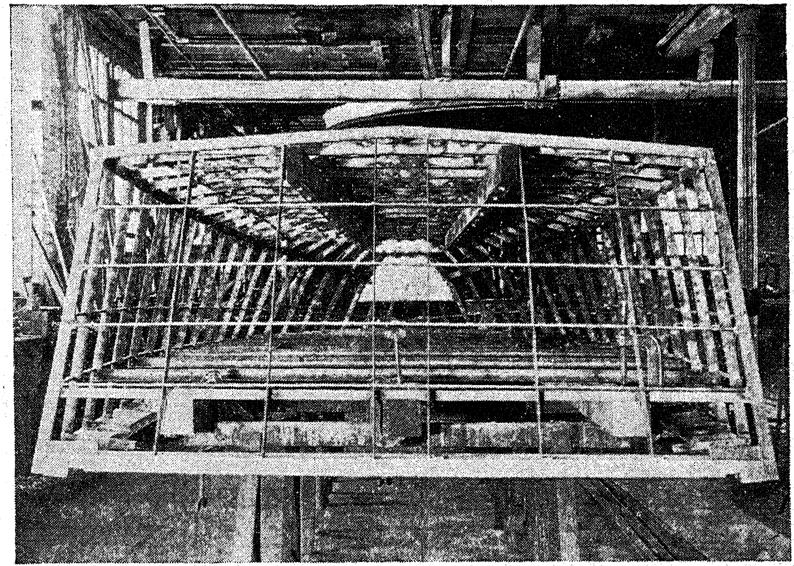

Fig. 2. Arc welded steel-framed hull.

Construction Details for Welded Steel Boats.—Having explained why our welded steel boat is 20% lower in building cost, 50% lower in maintenance costs, 20% more efficient, 10% faster, incomparably stronger and safer and about 1000% longer lived than the wooden boat, we will give the more important details on how they may be constructed.

Elimination of Vibration.—Vibration was the most serious of our troubles and its complete elimination from small boats of light weight was the greatest problem in the development of welded steel boats. Our first experimental boat was sheathed with 16-gauge iron over ribs spaced 1-foot apart. This left panels of 16-gauge steel about 33"x12" throughout the bottom and sides. Each and every one of those panels, except those near the bow where there was a pronounced curve in the sheets, vibrated excessively. We introduced small longitudinal ribs to break up the size of our panels to approximately 12x11 inches. This cut down vibration trouble about 75% but still more bracing and reducing of panel sizes was required in the flat sections of the aft bottom.

Our next boats used ribs of 1¼"x3⁄16" band iron on edge. These were spaced 12 to 13 inches apart with ½"x¼" notches cut at intervals of 7 or 8 inches. Longitudinal ribs of ½"x¼" iron were laid (on edge) in these notches making a framework which had no panel larger than 13x8 inches in the topsides and no larger than 13x7 inches in the bottom. (See Figs. 2 and 3).

Tests of these boats showed absolutely no panel or hull vibration whatsoever and the boats were more quiet than heavy wooden boats. In order to further dampen any tendency towards metallic sounds from any part of the hull it was found that well painted surfaces showed marked improvement over unpainted ones. Another aid in the elimination of vibration was the use of asphalt, or other waterproof plastic compounds, which could be melted and poured into various parts of the boat's bottom. In the topsides of early boats, where vibrating panels gave trouble, the condition was corrected by use of plastic cement or heavy paint into which was laid pieces of canvas fit neatly into the troublesome panel.

Protection of Steel and Methods of Preventing Corrosion.—The fear of corrosion in the prospective boat buyer's imagination greatly exceeds the actual danger in the boat. The use of galvanized iron sheets for sheathing steel boats has proved its practicability not only in riveted boats, which are still in use after 30 years, but in our own early welded boats which were subjected to most severe tests in salt water with bronze propellers and other bronze fittings attached to the hull purposely to hasten corrosive action that we might more easily study its action.

It was inevitable that small areas of steel would be exposed where the zinc coating of the galvanized sheets was burned off by the heat of welding. Actual tests in salt water for many months proved that the proximity of large areas of zinc partially protected these exposed parts and their corrosion was negligible. It was only about 2% as rapid as any small area of exposed steel under a wooden boat where the area of bronze in the propeller exceeded the amount of exposed steel. The successful painting of galvanized sheets was accomplished by the use of a chemical preparation. Over this preparation, aluminum paint showed the best adhesion after which other paints could be applied with excellent results.

The most satisfactory method of complete protection was obtained by spraying molten zinc into the freshly sandblasted surface of the

metal hull. This surface, after application of the chemical preparation, formed a perfect holding surface for paint and such hulls have shown years of service under all conditions with absolutely no sign of corrosion or paint peeling. In the case of an old hull which had been badly rusted and pitted by severe tests without any protection, this metalizing process was used to build up a coating of pure zinc on the pitted surface of the steel. This zinc coating was applied as thick as one thirty second of an inch on certain spots where the steel was badly in need of repair. This boat passes every test today and gives every indication of lasting indefinitely.

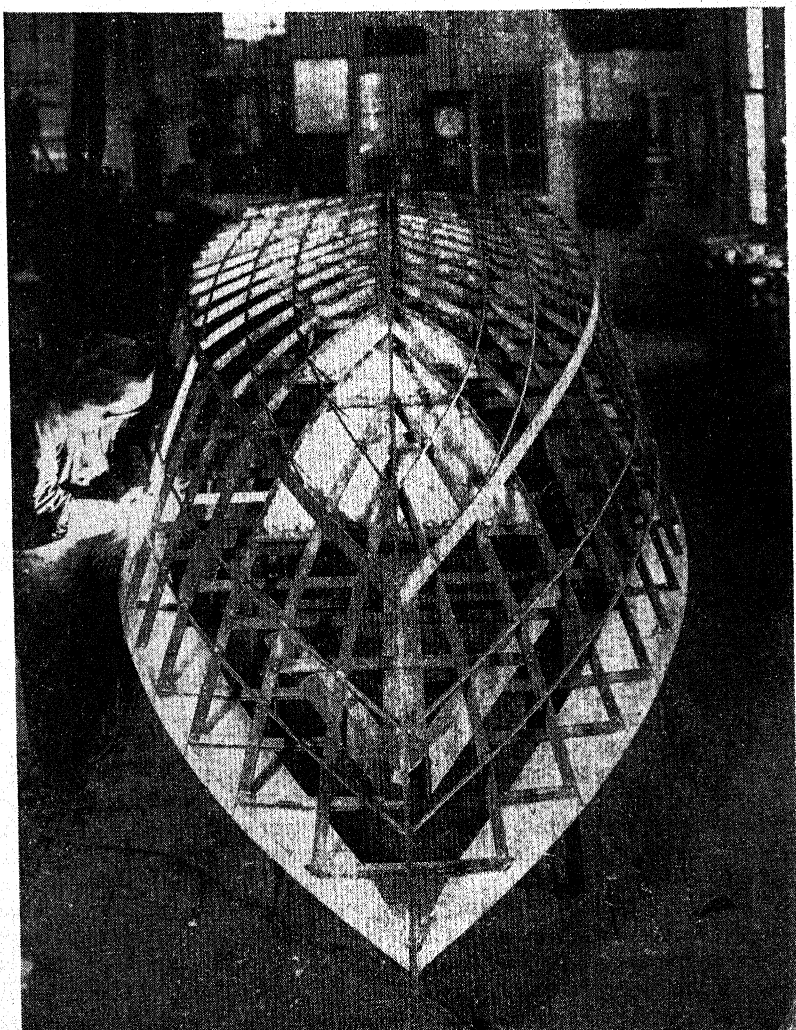

Fig. 8. Layout of parabolic grid.

Because of the fact that the inside of a welded steel hull may be kept absolutely dry, or nearly so, it is not necessary to metalize the inside of the hull at any other than small compartments near a stuffing box or other opening where a small leak might occur at intervals.

Boats in which no other protection than paint is intended should be sheathed with plates which have been previously "pickled" to remove mill scale. Various metal primer paints are available for doing a very thorough job of protection which will last as long or longer than the best paint job that is possible on a wooden hull. A full season's use in fresh water is possible with one painting of a metal hull.

Latest Improved Method of Construction Permits Any Desired Shape to be Built in Welded Steel.—For large cruisers and yachts, the popular demand insists upon the graceful flared-bow sections which show a very pronounced hollow curve through their transverse section combined with the natural convex curve of the longitudinal section and, with it all, the inevitable twist which completes the impossibility of sheathing such a surface in one piece as we did on an earlier and more simple convex model.

Attempts to sheath a well flared bow in strips, either longitudinally or diagonally, always resulted in an unsatisfactory job because the strips assumed the natural tendency towards a convex curve. Thus, the hull showed the series of bulged strips clearly accented by the welded seam which appeared as shallow V-shaped grooves.

In the latest method the sheathing is cut in strips running lengthwise same as wood planks. These strips are cut extra wide to allow for edges being turned in to form a shallow channel. The upper web of the channel is always a little deeper than the lower web. The frames are notched the same as if for stiffening battens. These frame notches receive the flanged edges of the channeled planking strip. As the edges of the plank are pressed tight and clamped together on the inside, it will be noted that the edges of the two channel flanges come together in such a way as to permit the welder to weld them easily from the inside in a naturally efficient position without having to work up or overhead.

Because the best of the weld is applied to the inside tips of the channel sections, instead of to the outside surface, the resultant shrinkage only serves to complete the desired longitudinal curve of the planking strip. Any tendency towards weld shrinkage causing the undesirable convex curve in the transversal section is negligible. If not, it is easily prevented by bending the channel before hand in the shape indicated to fit the desired concave section. This system will permit a welder to work faster and use more heat than was ever possible when working on an outside surface.

When welding on outside surfaces, in order to prevent buckling and warping of sheets, it is absolutely necessary for a welder to work with extreme care and use the least possible heat consistent with a good weld. He must first tack the well-clamped sheet in a great number of places and then complete his seams by welding first on one part and then another, coming back to the place where he started only after the metal has cooled. It is impossible to start a good hot weld and

continue it along the entire length of a seam without stopping. If this were done, the sheet would creep and break away from its fastenings, opening up on the other side and buckling in such a manner as to completely ruin the job.

After the inside tips of the plank channel have been welded, the channels will actually fit the curve better than before they were welded. It is then possible to stiffen up the side by applying a very light bead, or series of intermittent tack welds, along the outside seam. As explained in the next paragraph these welds should be lighter and secondary to the main watertight weld inside. This is so that under excessive stress, as in collision or other breaking strain, the outside welds may let go and permit the opening up of the section as shown in the drawing, Fig. 4.

Unusual Safety Feature Provided by New Method.—Since the possibility of collision is ever to be considered, and since the force of a collision blow may easily be greater than the power of resistance regardless of how strongly a vessel may be constructed, it would naturally be of great advantage to have the resultant hole in the vessel's side as small as possible.

Our steel sides possess the ability to take ordinary blows with no greater damage than a harmless dent which is easily hammered out and repaired. But when we consider the collision blow too great to be resisted, we find the outer skin tending to tear open as it is stretched beyond its elastic limit.

The new method invented and patented by the writer, (See Fig. 4), provides at this point a much greater reserve of elastic limit. So much greater factor of safety is provided by this increased elasticity under breaking strain that in case of a collision which might admit the bow of a colliding vessel or rock several feet into the hull of our welded boat—enough perhaps to break frames and crush bulkheads—we find that our elastic outerskins open up like the folds of a plaited garment and remains unbroken though badly dented. We admit, of course, that while it is possible to punch a hole in such a side or bottom, it is quite obvious that with this great reserve of flexibility, the resultant hole, if any, will be only a small fraction as large as it would be if the side were one taut sheet of steel which would have to tear open as it reached its elastic limit.

So great are the several advantages of this method of sheathing a welded steel hull, that it will be found advantageous on all parts of the sides and bottom of a vessel whether surfaces be concave or convex or flat.

If the use of thin sheathing, or other consideration, dictates the leaving of a partly open seam on the outside of the hull it may easily be filled with a suitable waterproof plastic compound same as wooden boats. The steel boat seam, however, will not be subject to the many troubles of the wood boat seam because there will be no shrinking or swelling of the steel planks. The cemented seam may, therefore, be smoothed to the point of being almost invisible and remain so indefinitely.

The advantages of our reserve flexibility in hull construction do not apply to decks or cabin roofs which can best be made in the original

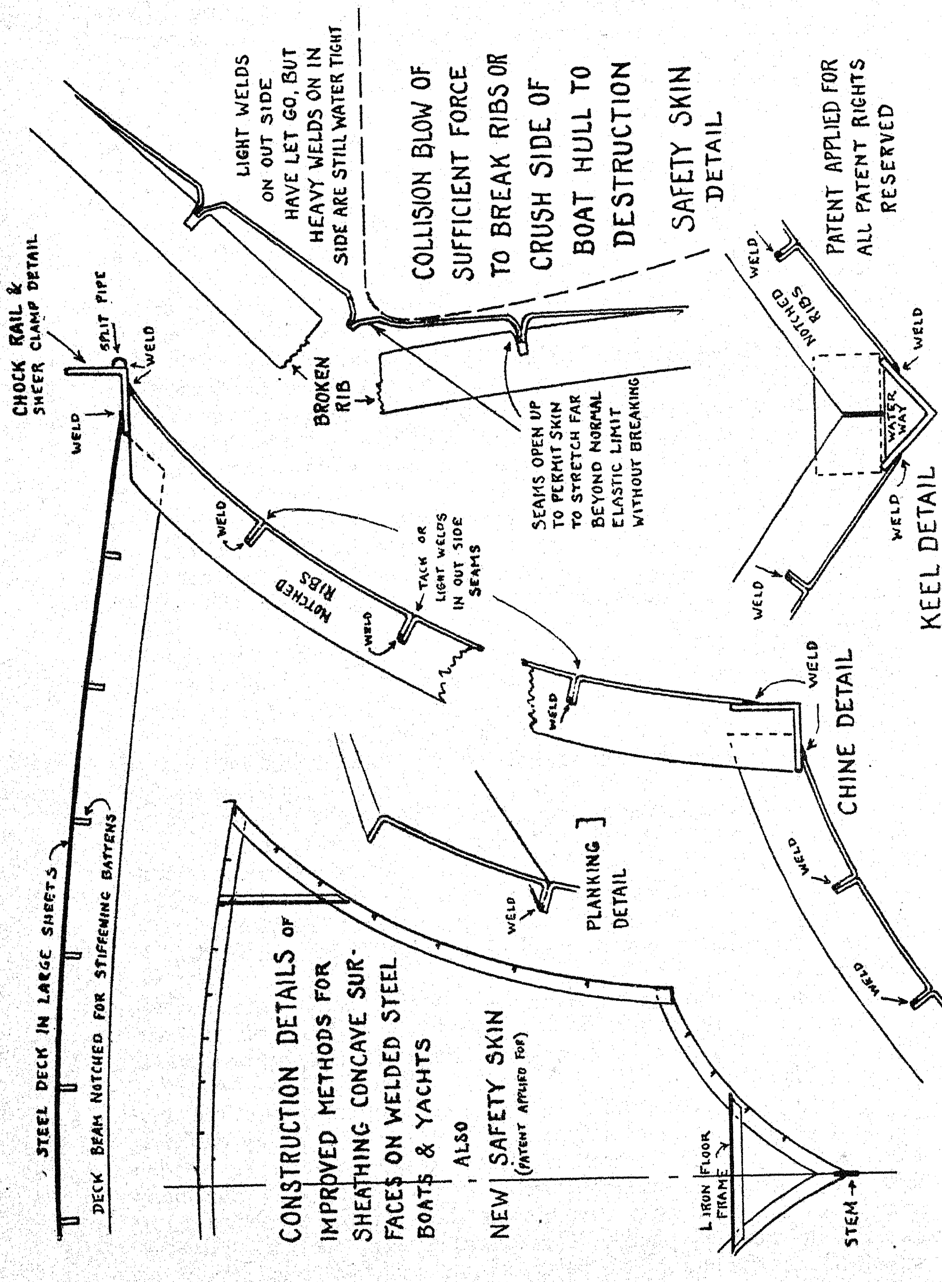

Fig. 4. Details of arc welded boat frame which utilizes steel strips turned in to form channels.

big sheet over ribs and battens. The natural convex surface of decks and roofs are comparatively easy to build and to weld in this manner.

Other Improvements Over Original Methods.—Early welded steel boats of the Vee-bottom type used bars or straps for keels and chines. But the two separate seams, or one heavy welded seam, required to make the hull watertight, often caused some buckling of bottom and side sheets. To overcome this, we used an angle iron 2½x2½x⅛ inches for a chine as indicated in Fig. 4. This separated the two strips of welding by about 4″ and also provided flexibility between the side and bottom sheets. The light angle iron could open or close slightly in case of great strain or heat variation and its use helped to eliminate buckled sheets by about 50%. In addition to the gain mentioned, it saved the labor of cutting a notch for the chine. Moreover, it saved weight. Best of all, however, it improved the design of the boat by providing the proper "snap off" at the chine to throw the water out and away horizontally instead of permitting it to rise along the side. This improvement is clearly shown in photo of "Vega," Fig. 5, which has the angle iron chine.

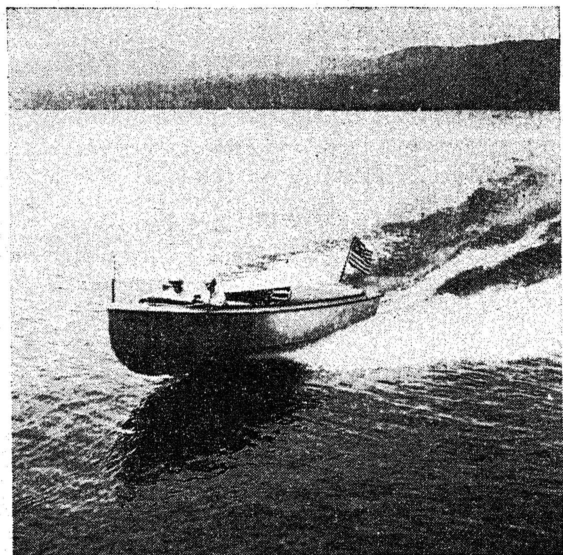

Fig. 5. Use of angle-iron chine enables boat to throw water out and away instead of permitting it to rise along the side.

So well did this angle iron chine serve its purpose that we then adopted the same idea to our keel. We used a 2x2x¼″ angle iron and brought it as far forward as the shape of the bow permitted. This not only gave us welding advantages and simplified fitting of bottom sheets, but it also provided a small sharp keel to aid in obtaining just the proper amount of lateral resistance for a boat of the 30-miles per hour variety.

Other New Types of Motor Boats Made Possible by the Use of Welded Steel.—The greatly superior strength of the welded steel hull, with less weight and less inside bracing than was required in wooden hulls, has led the author to design new shapes for boat hulls which would use this strength to advantage by eliminating useless deck structures and making hull and cabins all in one streamlined structure which would permit about twice as much interior accommodation in a hull of given length. This could be accomplished at a saving of over 30% in weight and more than 35% in building costs. The resultant savings in economy of operation and lower cost of maintenance would be even greater than the figures given in our previous examples. The advantages of reduced wind resistance and elimination of parasite resistance would add still greater advantages in speed and economy.

To prove this part, the author designed and built a ½-size scale model of his proposed 35x11-foot cruiser. This boat was 17′6″ long and 5′6″ wide. It was built mostly of duraluminum and welded steel. It was powered by a 6 cylinder motor of 225 cubic inch displacement. This boat was raced throughout the season of 1937 and not only won the 225 division of famous Albany-New York Marathon, where only 41 boats out of 115 starters succeeded in reaching the finish line, but she also distinguished herself in the Absecon Island race at Atlantic City where boats of unlimited power raced at mile-a-minute speeds in the open Atlantic Ocean. This boat also won second place in the Quebec championships and third in the Canadian International Championships at Picton, Ontario.

It is worth nothing that not one of the welded seams let go. This boat was not all welded, however, and the riveted seams and the riveted-and-soldered seams, as well as the joints where duraluminum was screwed, bolted or nailed to oak and mahogany frames, did give us much trouble. They had to be repaired after every race where speeds of over 60 miles per hour caused such seams to break loose.

SECTION V

STRUCTURAL

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SECTION V
STRUCTURAL

Chapter I—The All-Welded Diagonal Grid Applied to Plane and Spatial Structures

By ANANT H. PANDYA and R. J. FOWLER,
Engineers, Diagrid Structures, Ltd., London, England. Complete paper contained 19,000 words, 105 illustrations.

The elastic properties of steel as a building material and the possibility of joining members in a monolithic and continuous manner are the two primary considerations governing the design of modern structures. The all-welded monolithic grids for plane and spatial structures which form the subject of this paper are thus introduced in the mosaic-like pattern of present-day life, as they exploit modern engineering theories and technique to the full, and, consistent with economy, they produce results demanded by human progress.

Development of the Ideas of Monolithic Grids and the Advantages They Offer.—Building of steel structures with riveted or bolted connections has been known for nearly a century, and various methods of design have been developed to this end. Suitable types of members have been manufactured and a variety of connection details have been evolved in an attempt to make the best use of the material.

The application of arc welding to steel structures on any considerable scale, can be said to have come into being after the last World War. This fact suggests the possibility and indeed the necessity of a closer investigation into the opportunities now available to us. The experience of engineers all over the world has already revealed the inadequacy of methods developed for riveted work when applied to welded structures. This is, in fact, only natural as the new technique is so revolutionary that only a completely new orientation of our methods would make it possible for us to utilize this with the fullest advantage. It has also been apparent that endeavors should be made to produce entirely new types of structural arrangements that are especially adapted to welding.

The monolithic grids, which are described in the following pages, constitute an important step forward in that direction, as they embody an idea unknown before the last War, and which at the same time relies entirely on the properties of welded connections. The grids under consideration are all-welded and cannot, in fact, be fabricated with riveted connections, as complete continuity is a prerequisite for its design.

These grids can be arranged in almost any size or shape and can be adapted to plane or spatial structures. The methods of analysis, while employing the most advanced theories, are simplified to such an extent that most engineers can follow them with ease. There is, thus, no limit to the application of these grids, and it can be confidently

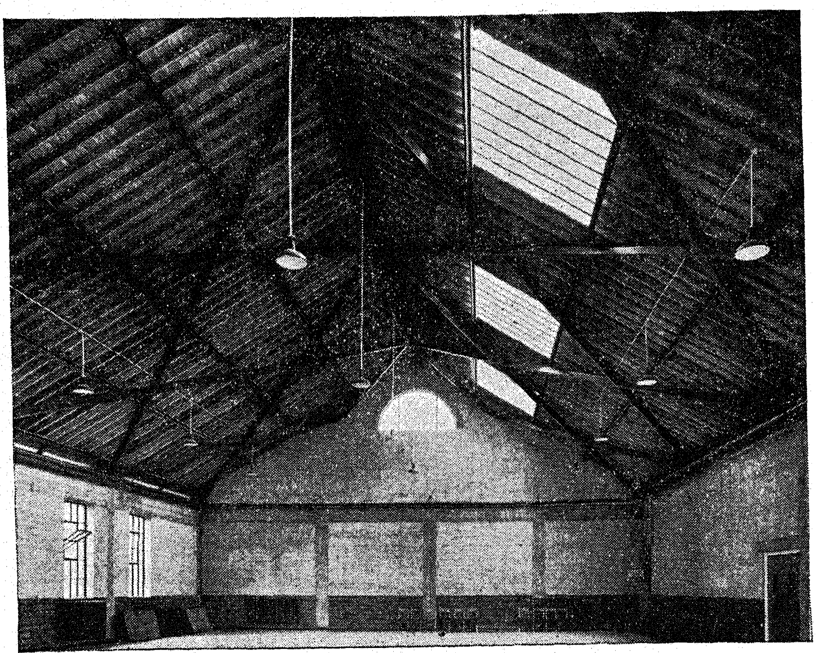


Fig. 1. All-welded diagonal grid in 82' x 52' single pitch roof of Drill Hall, London.

predicted that they will help steel to hold its own against other competing building materials.

For buildings in general and industrial structures in particular, the following properties are demanded by modern conditions of life. They are briefly:

(1) Lowest possible first cost.
(2) Low cost of maintenance.
(3) Attractive architectural appearance.
(4) Simplicity and cleanliness of construction.
(5) Freedom from internal columns, deep beams, etc.
(6) Freedom for planning of partitions, machinery, etc.
(7) Improved lighting and ventilation.
(8) Adaptability for future expansion or for conversion of structure for altered conditions of use.
(9) Speed and ease of erection.
(10) Maximum strength for unit weight of material, especially against aerial attack.

It is claimed here that the grids under consideration, fulfil every one of the above requirements. A number of actual structures built after January 1st, 1937, are described in later pages and they all demonstrate the properties listed above in varying degrees, when compared with ordinary structures.

Apart from an estimated saving in first cost of 10% to 30%, depending on the size and layout of the structure, there is an estimated saving of 30% to 40% in maintenance costs where steelwork is ex-

posed. Considering the vast amount of money spent every year all over the world on structures of all types, it is difficult to estimate the exact cost saving which would follow the widespread use of these grids for floors and roofs, but the magnitude would, however, be very considerable. Further data on costs are given later.

As regards pleasing appearance, simplicity and cleanliness of construction, freedom from internal columns and deep beams, improved lighting and ventilation etc., which all tend to increase efficiency and social amenities, some idea can be had from the photographs of structures, Figs. 1, 2, and 3. These are dealt with in detail and compared with previous methods of construction in later pages.

Particular attention must here be paid to the multiple ridge and valley type of grid-roof structures, and a comparison is now made with normal design of industrial structures of this type.

For industrial structures in which articles or materials of considerable bulk are to be handled, it is necessary to have large clear spans which also are often dependent on the proper flow of work through the plant. This is usually arranged by using heavy and complicated lattice girders in the depth of the roof, which in turn carry the roof trusses and are themselves supported by columns at frequent intervals. In some cases, such as aircraft factories, it is imperative to have clear spans up to or exceeding 250 feet. This can usually be achieved by orthodox methods at great cost and a somewhat complicated and clumsy arrangement of steelwork in the roof.

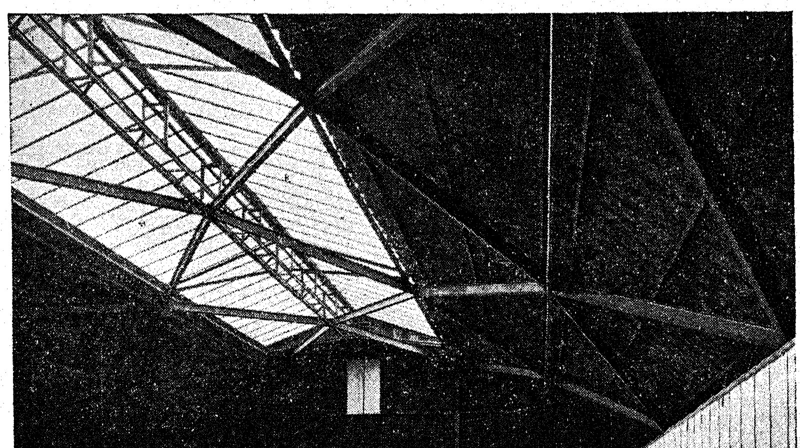


Fig. 2. Parabolic arched grid roof of Badminton Hall, Epsom, England.

Great spans are also desirable if there is any likelihood of a rearrangement of the factory layout, or if the machinery itself is to be replanned at a future date. In such circumstances, internal columns are a great inconvenience and a positive hindrance to such re-planning.

In the design of industrial structures, therefore, true economy can only be attained when the structure is easily adaptable to future, as well

as present, requirements of a growing industry. Ease and facility of extension and alteration are thus of primary importance in most industrial structures, and the grid idea finds its best application in such cases because it eliminates internal columns at reasonable cost.

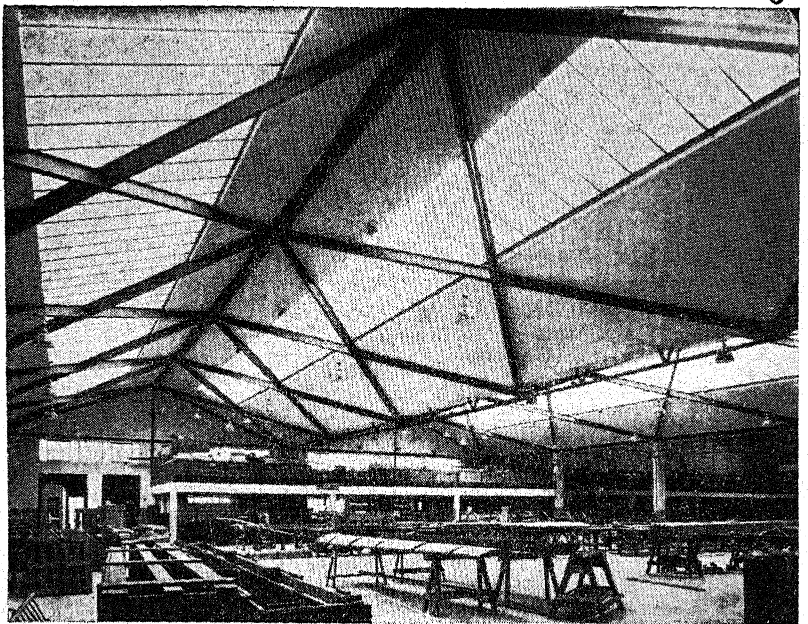


Fig. 3. Complete absence of internal supports in factory building at Bristol, England.

The design of north-light type structures, so often demanded because it excludes direct sunlight, is normally arranged in one of the following manners:

(1) The heavy lattice girders which form the backbone of the structure are placed vertically under the ridges and the roof is supported by intermediate secondary trusses placed at right angles to them at frequent intervals.

(2) The lattice girders are arranged against the north-light glazing area and are kept in position by heavy rafter construction and a system of tie rods introduced at the apex of the roof.

(3) The third and somewhat uncommon form is to arrange the lattice girders at right angles to the glazing area, and involves the partial exposure of the upper boom or chord members of these girders, which is most unsatisfactory from the point of view of maintenance.

The spatial grids provide an ideal solution for such structures, and the authors believe that a comparatively light grid will serve its purpose more efficiently and economically than anything known so far.

Principles of Design.—The most important result of arc welding when applied to steel structures is to produce a monolithic action be-

tween the various members connected together. The continuity thus obtained is a great asset from the economic point of view, as it tends to reduce moments and forces acting on the component parts of a load-bearing structural system. It leads, however, to a structure which can be designed only by the use of somewhat complex methods of stress analysis.

The object of engineering science is to produce a structure most suitable for the use to which it is to be put and which is also the most economical in first cost and subsequent maintenance. This dual purpose can be served very efficiently by continuous structures, which by their very nature are simpler in detail, neater in appearance and lighter in weight than structures designed on orthodox lines.

It is a matter of common knowledge that the classic work of Castigliano entitled "Theorie de l'equilibre des systemes elastiques" and published in the year 1879 forms the basis of the present theory of elasticity. It can be stated categorically that the proper and complete application of this well known theory would meet most of the demands of modern structural design and would lead to great economic benefit.

The plane and spatial grids which form the subject of this paper are fully monolithic and are therefore hyperstatic or statically indeterminate systems necessitating the use of the theory of elasticity. In their analysis, the following methods commonly recognized as Slope deflection, Least work, Virtual work, Strain energy, etc. are employed.

Before considering the more complicated spatial structures, the plane grid (suitable for floors and flat roofs) will be examined, the spatial structures being merely an extension of the fundamental co-operative properties of the flat grid.

The best way of approaching the solution of a monolithic grid system is: first to assume simple support conditions and independence of action for all grid members, and then to superimpose the effects of the indeterminate forces and moments to restore continuity or internal restraint. This would follow from the principle of superposition which states that the effect produced upon an elastic structure by a number of forces and moments which act simultaneously, is the same as the algebraic sum of the effects produced if the forces and moments are assumed to act separately.

Plane Grid.—The grid under consideration comprises essentially a diagonal system of beams (usually having the same cross-section) which are arranged in two parallel sets equally spaced and intersecting at 90° or nearly so, and rigidly connected at the junctions or nodes. This layout gives, in all cases, beams of varying span, and therefore of varying rigidity, if treated as independent of each other. When connected monolithically, those more rigid give great relief to those more flexible, and thus tend to equalize the moments and shear forces on all beams.

Referring to Fig. 4, this illustrates a typical diagonal grid bay supported on walls, columns or main beams along the boundaries only. (The shorter side of the bay is divided into three and the longer into five equal divisions.) It will be observed that the beams intersecting at the internal grid nodes not lying on an axis of symmetry would,

if independent of each other, deflect by a different amount under symmetrical loading. In fact, however, these deflections at any node must be equal, which means that at every non-axial node equalizing forces P act between the intersecting beams. There is, also, at the edge nodes the condition of equal and slope angles for both intersecting beams, which results in the occurrence of equalizing moments M. In addition to the above forces P and moments M which arise from the flexural rigidity of the individual beams, there are torsional equalizing moments T acting at internal non-axial nodes arising out of the condi-

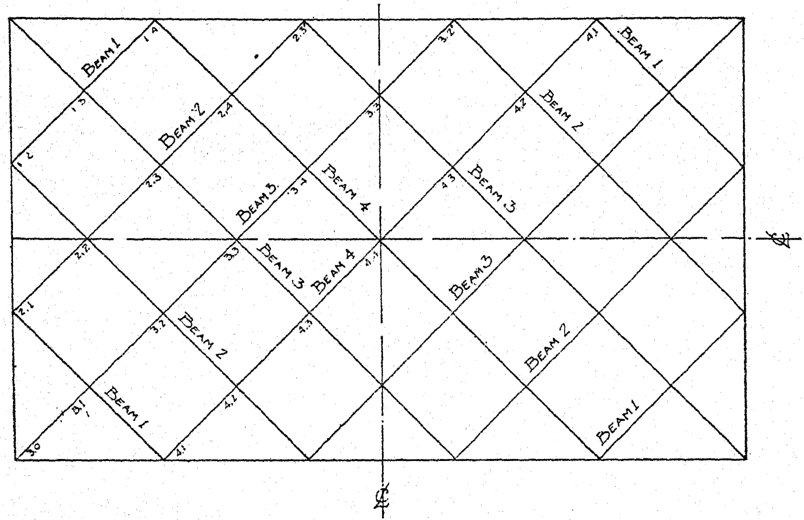


Fig. 4. Layout of plane grid.

tion that at any such node the twist angle of one beam must be equal to the slope angle of the beam it intersects. It may, however, be mentioned here that these torsional effects are quite negligible in practice when ordinary rolled steel sections are used as grid members.

These statically indeterminate forces P and moments M are evaluated from the following facts. At each node where one of the unknown forces acts, the total deflections δ of the two beams due to superimposed load, and the unknown forces and moments are equal. Similarly, at each node, where one of the unknown moments acts, the total slope angles θ of the two beams due to the same causes are equal. Thus, there are as many independent deformation equations available as there are unknown quantities.

Before these equations can be set up it is necessary to calculate deformation coefficients for all individual beams due to unit values of P, M, and w the superimposed load from the following fundamental relationships:

Slope θ at any point $= \int \frac{M}{EI} dx.$ and

Deflection δ at any point $= \int \int \frac{M}{EI} dx\, dx.$ where the integrations are between suitable limits.

This can also be done conveniently by the moment-area method in which the moment diagram is treated as a load diagram and the shear forces and moments due to this imaginary loading provide slope and deflection values respectively for any desired point.

The statically indeterminate quantities are then introduced in deformation equations which take the following form, i.e. for point 1, 3 (See Fig. 4):

$$\delta_1^{w} + \delta_1^{P_1} P_1 + \delta_1^{P_2} P_2 + \delta_1^{P_3} P_3 \ldots\ldots + \delta_1^{M_1} M_1 + \delta_1^{M_2} M_2 \ldots\ldots$$

$$= \delta_3^{w} + \delta_3^{P_1} P_1 + \delta_3^{P_2} P_2 + \delta_3^{P_3} P_3 \ldots\ldots + \delta_3^{M_1} M_1 + \delta_3^{M_2} M_2 \ldots\ldots$$

and for point 2,3′ (see Fig. 4)

$$\theta_2^{w} + \theta_2^{P_1} P_1 + \theta_2^{P_2} P_2 + \theta_2^{P_3} P_3 \ldots\ldots + \theta_2^{M_1} M_1 + \theta_2^{M_2} M_2 + \theta_2^{M_3} M_3$$

$$= \theta_3^{w} + \theta_3^{P_1} P_1 + \theta_3^{P_2} P_2 + \theta_3^{P_3} P_3 \ldots\ldots + \theta_3^{M_1} M_1 + \theta_3^{M_2} M_2 + \theta_3^{M_3} M_3$$

etc........where δ_1^{w}, $\delta_1^{P_1}$, $\delta_1^{P_2}$ ....$\delta_1^{M_1}$, $\delta_1^{M_2}$ and δ_3^{w}, $\delta_3^{P_1}$, $\delta_3^{P_2}$ ....$\delta_3^{M_1}$, $\delta_3^{M_2}$ etc. ....are deflection coefficients for beams 1 and 3 respectively due to unit values of w, P and M. Similarly, θ_2^{w}, $\theta_2^{P_1}$, $\theta_2^{P_2}$ ....$\theta_2^{M_1}$, $\theta_2^{M_2}$ and θ_3^{w}, $\theta_3^{P_1}$, $\theta_3^{P_2}$, ...$\theta_3^{M_1}$, $\theta_3^{M_2}$ ....etc. are slope coefficients for beams 2 and 3 respectively due to unit values of w, P and M.

These equations when arranged properly exhibit a remarkable symmetry which follows at once from the well known theorems of reciprocal slopes and deflections, and serves as a good check on the correctness of the values of deformation coefficients. They can then be solved by the exact method of successive elimination due to Gauss or by the approximate method of iteration. For the sake of brevity, no attempt is made here to work out a numerical example—although in practice this is a very simple operation if attacked systematically.

Having obtained the values of the statically indeterminate moments and forces, the final moments, shear forces and reactions for all grid beams are obtained by simple statical considerations (See Fig. 5).

It will be observed from Fig. 5 that all the grid beams are subjected to moments and shear forces which tend to attain a uniform maximum value, thus illustrating the true co-operative action between the grid beams. It will also be noticed that for any given layout the actual spans and loading can be varied without the necessity of a new calculation. This leads directly to the possibility of achieving standardization of

calculations which are independent of the variables, span and load, and which once made can be applied to a variety of conditions. Furthermore, the selection of the size of grid beams can also be made in a few minutes from the maximum moment factor for a given layout.

The diagonal arrangement of grid beams also has the following advantages:

(a) A shallower depth of construction due to the elimination of deep main beams.
(b) A plane soffit for floors or flat roofs.
(c) Economy due to the fullest exploitation of continuity.
(d) Rapidity and ease of construction due to the great measure of standardization and simplification achieved.
(e) Use only of rolled instead of plated sections to cover large spans.

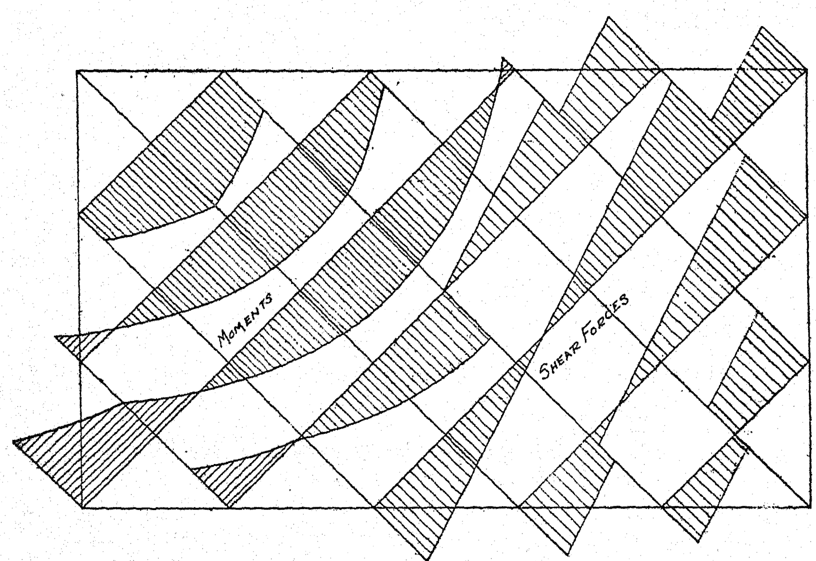


Fig. 5. Moments and shear forces on plane grid.

By the application of the method already discussed, other layouts can be analyzed for single or multiple continuous floor bays. The magnitude of moments and forces, the selection of beam sizes, connection details, methods of erection, and examples of structures already erected, will be dealt with later.

Single Pitch Grid Roof.—For roof spans exceeding 50 feet it is common in normal design to make use of space frames, arches, trusses, etc., to support the roof covering, and the superimposed loads due to snow, wind, etc. In effect, the depth of construction is increased in order to evolve a practical and economical design.

For monolithic grids the same results can be obtained by folding a plane grid to form a ridge along the centre line and two gable ends with horizontal ties as shown in Fig. 6.

The grid, instead of being made up of interlacing straight beams, now consists of a number of cranked beams which are fully continuous at the cranking points and are capable of transmitting moments from one side of the crank to the other.

These cranked beams are, by reason of their slope, subjected to direct forces (compression or tension) with horizontal components H, in addition to the forces and moments causing bending as discussed for

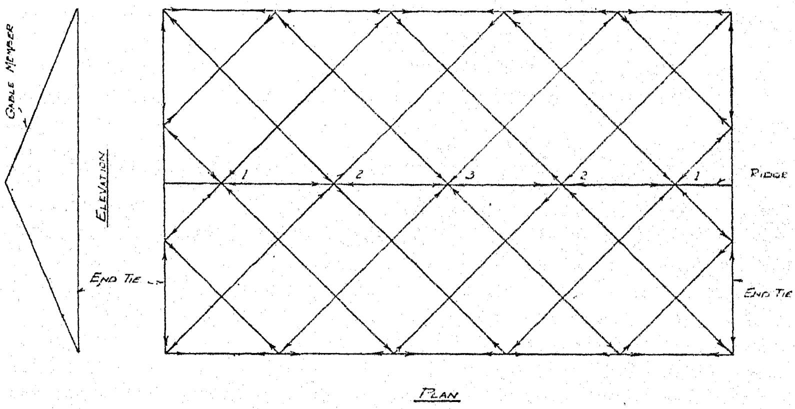


Fig. 6. Layout of single-pitch roof.

the plane grids. These forces H are therefore to be considered as additional unknown quantities. It is assumed that the columns or walls supporting the pitched roof are incapable of withstanding these horizontal forces, which, in the absence of any intermediate ties, implies that at every edge node the horizontal forces for the two intersecting beams must be equal and of opposite sign. Moreover, the central ridge must, because of the shape of the roof, be in compression.

The procedure for finding the above unknowns H is briefly as follows:

The horizontal forces H, as already mentioned, are additional unknown quantities acting on the basic system, i.e. the plane grid considered above, and their effects on the system are found by deformation equations in the same manner as those due to the superimposed load. The moments on the cranked beam due to unit values of H having been obtained, the actual magnitude of forces H is found by applying the principle of least work, as follows:

The expression for the total work stored in the entire system neglecting that due to shear forces is:

$U = \Sigma\int_0^L \frac{M^2dx}{2EI} + \Sigma \frac{F^2L}{2EA}$ where for any member of the system:

M = Actual moment at any point,
F = Actual force in member,
I = Moment of Inertia,
A = Sectional area,
L = length,
E = Modulus of elasticity.

It may further be stated that in the above expression for U = the work stored in the system:

$M = M_0 + H_1 M_{H1} + H_2 M_{H2}$ .... and $F = F_0 + H_1 F_{H1} + H_2 F_{H2}$ .... where for the basic system:

M_0 = Moment due to superimposed load,
F_0 = Force due to superimposed load,
M_{H1} = Moment due to $H_1 = 1$,
M_{H2} = Moment due to $H_2 = 1$, etc.,
F_{H1} = Force due to $H_1 = 1$,
F_{H2} = Force due to $H_2 = 1$, etc.

Differentiating the expression for U with respect to H_1, one of the unknowns,

$$\frac{\partial U}{\partial H_1} = \Sigma \int_0^L \frac{M \partial M}{\partial H_1} \frac{dx}{EI} + \Sigma^F \frac{\partial F}{\partial H_1} \frac{L}{EA},$$

which must be equal to zero. In practice the above integrations can be computed with ease by methods developed by Professor Müller-Breslau in his book; *Die Graphische Statik der Baukonstruktionen.*

Similar partial differentiation of the expression for U with respect to the other unknowns H can be carried out and as many equations as the number of unknowns set up. From these equations, actual magnitudes of the horizontal forces H are first obtained and then the final moments and forces on the different members are worked out (See Fig. 7).

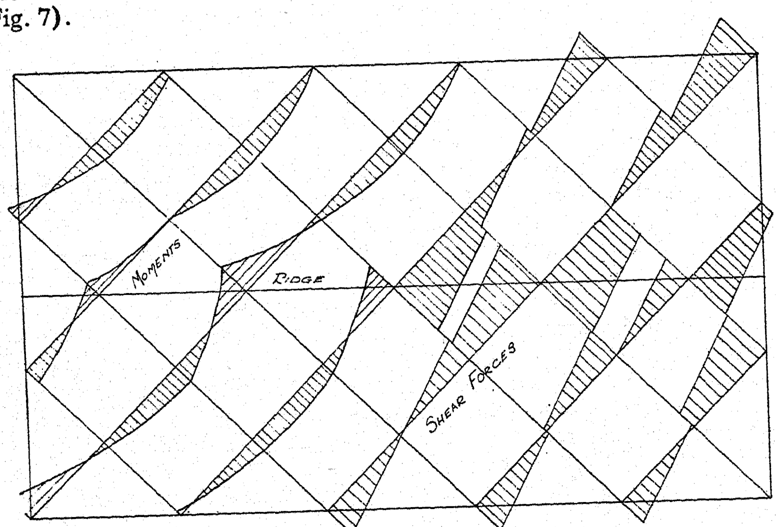


Fig. 7. Moments and shear forces of single pitch roof.

Having outlined the method of analysis, we shall examine in a simple manner the effect of cranking the plane grid. From the moment diagram in Fig. 7, it will be observed that this introduces virtual elastic supports for grid members at ridge nodes which are, in their nature, similar to internal equalizing forces acting upwards on the grid beams and downwards on the inclined lattice or rhombic girders formed by the

grid beams and ridge and eaves members. These imaginary supporting forces reduce the moments and shear forces on the grid beams very considerably, and transfer the superimposed loads to the actual points of supports along the boundaries by means of direct forces in the members.

The lattice girder action referred to above immediately suggests an alternative approach to the solution of this problem. Identical results can be obtained by the method of deflection which makes use of the fact that the work stored in the whole system is equal to the external work done on it provided the supports are rigid.

Referring again to Fig. 6 the system of members can be looked upon simply as two inclined lattice or rhombic girders connected together at the ridge nodes and prevented from spreading out by means of end gable ties. The girders or trusses spanning longitudinally have grid beams as diagonal web members and ridge and eaves members as booms or chords. The superimposed load is here carried by the web members which in effect span between the eaves and ridge lines and are also continuous at the ridge nodes. These internal grid node points lying along the ridge line coincide with upper internal boom points of the trusses. At these points, therefore, there would be introduced a number of equalizing forces P which are statically indeterminate. These forces can be found by deformation equations obtained from the fact that at any internal ridge node, the deflection of the truss boom due to the equalizing forces P equals the sum of the deflections of the grid beams due to the superimposed loads and the equalizing forces P, i.e. for point 1:

$$P_1 \, \delta_{t1}^{P_1} + P_2 \, \delta_{t1}^{P_2} \, \ldots\ldots = \delta_1^{w} - P_1 \, \delta_1^{P_1} \, \ldots\ldots \text{ where:}$$

$\delta_{t_1}^{P_1}$ $\delta_{t_2}^{P_2}$ ...... are the truss boom deflections at the point 1 due to unit values of forces P and δ_1^{w}, $\delta_1^{P_1}$ ...... are the plane grid deflections due to unit values of the superimposed load w, and the equalizing forces P respectively.

Similar equations can be set up for the other ridge node points and actual values of forces P determined.

The truss boom deflections can be found from the following relationship:

$$\delta_t = \Sigma \frac{F L f}{EA} \quad \text{where}$$

δ_t = Truss boom deflection,
F = Force in member,
L = Length of member,
f = Force due to unit load applied at point under consideration.
E = Modulus of elasticity.
A = Cross Sectional area of member.

After the actual values of forces P are determined, the final moments and forces on the different members can be worked out as before (See Fig. 7).

Arched Grid Roof.—The two alternative methods of stress analysis described above for spatial grid structures can be applied with equal ease to arch shaped roofs made up of a number of straight line segments.

Referring to Fig. 8, it will be observed that on plan both the shorter and the longer sides of the bay are divided into three equal parts, and the division points are connected in a diagonal direction. Transversely, the structure is folded into six planes, the cranking points lying on a parabolic curve. As in the case of the single pitch roof, the moments and shear forces on the individual grid beams are still further reduced by the presence of a greater number of cranking points. This leads not only to economy but to enhanced architectural advantages, which open up many fields of application for this type of roof.

Application of the Principles of Design to Various Layouts and Shapes.—The methods outlined previously were described, for the sake of clarity, only for very simple cases. Their application can, however, extend to much wider fields and can, indeed, embrace almost all sizes and shapes of floor and roof constructions met with in normal practice. The object of this chapter is to describe some of the numerous variations of the fundamental monolithic grid idea, and demonstrate how the principles of design already enunciated can be utilized with further advantages.

Plane Grids.—For the sake of illustration, in the earlier discussion a three, five division grid (See Figs. 1 and 9F) was selected. As illustrated in Fig. 9, however, for single bays the sides of the bay forming the boundaries can be divided into two, three, four, five or even six equal parts, the aim always being to provide short corner beams (beam 1 in Fig. 4) and an angle of intersection as near to 90° as possible. Sides

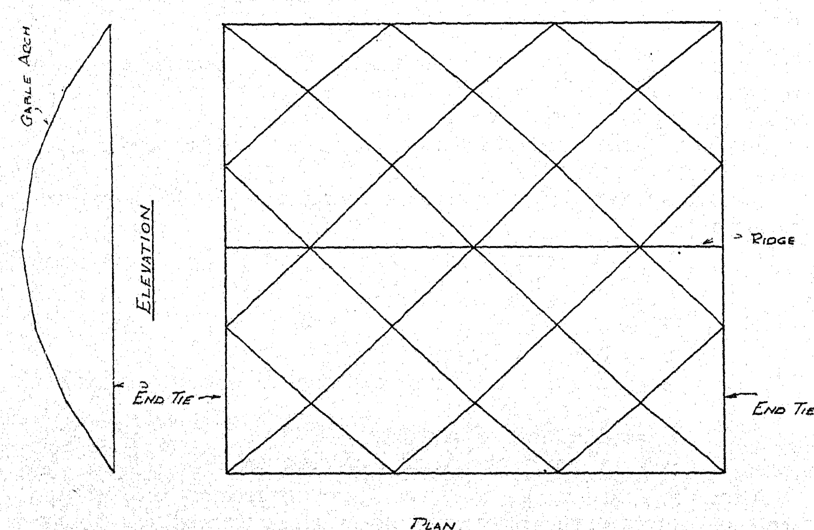


Fig. 8. Layout of parabolic grid.

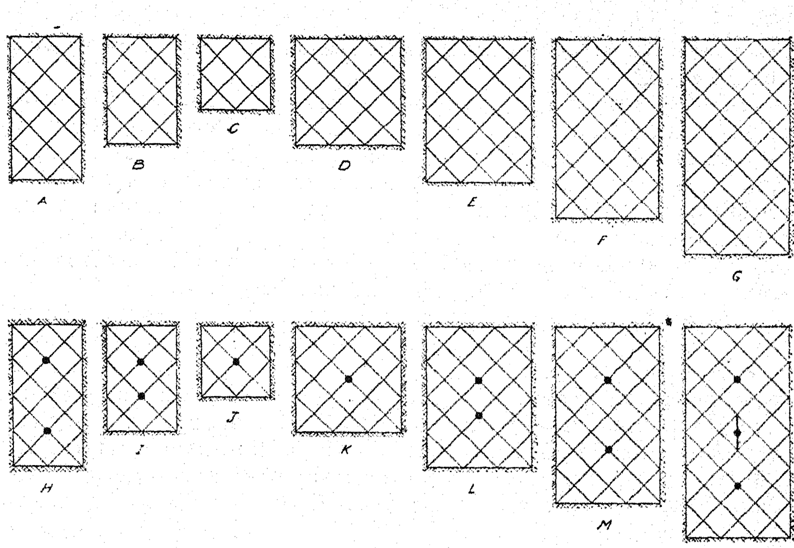


Fig. 9. Layouts of plane grids supported on all sides.

of square bays are, however, best divided into three equal parts which are found to be most economical in practice (See Fig. 9D).

That this should be so is suggested by the following considerations:

(1) There is a maximum of "corner action" in a three-three division grid because of the four short, stiff corner beams which in effect reduce the effective span of all other grid beams. In other words, the square grid bay is reduced to an octagonal bay of a much smaller size.

(2) The load from the centre of the panel is taken to the supports in the shortest and the most direct manner instead of a zigzag fashion when, as in orthodox design, a set of main and secondary beams is used.

(3) By a judicious arrangement of flooring or roofing material, (that is, reinforced concrete slab), the torsional rigidity of the shortest corner beams can be increased very considerably, and much smaller bending moments and deflections obtained for all the grid beams.

A further examination of Fig. 9 points to the many variations not only of the grid layouts but of the arrangements of internal supports if and when required in exceptionally large spans. Fig. 9N illustrates a central column with a cantilever providing two points of supports for the grid beams. Those in Fig. 9 are only a few of the numerous layouts possible for single panels supported on the boundaries by brick or masonry walls or by suitable arrangement of columns. The reactions in every case are purely vertical. It might be mentioned here that further economies can no doubt be obtained by fixing the plane grid at its boundary nodes to monolithic columns, thus obtaining a frame or portal effect, with consequent reduction in span moments.

Having treated single panels, attention is now drawn to series panels, that is, grid bays supported only on two sides but continuous along the other two, as illustrated in Fig. 10. These are especially suitable for long comparatively narrow structures with or without internal columns; where the absence of columns is essential transverse main

beams with a suitable spacing can be employed, as shown in Figs. 10A, B and C.

Depending on the general planning requirements, however, internal columns can often be introduced with economy. Here again, the total number of these can be reduced by using the cantilever idea in which two points of comparatively rigid supports are obtained by a cantilever resting on a central column. Where a facade clear of columns is required, the external walls or window framing can be supported on an edge beam which in turn would be supported by transverse main beams resting on columns which are set back from the facade.

The next step in the development of monolithic grids is the application to continuous grids as illustrated in Fig. 11. It will be readily observed that Figs. 11A, B and C indicate a marked similarity to mushroom or flat slab layout. This is accentuated by the fact that a set of crossed cantilevers is used with each column, which appears to be comparable to drop panels and column heads in mushroom design. The grid beams, on the other hand, are similar to the cross or two-way reinforcement commonly used in reinforced concrete flat slab construction.

This then brings us to the most important and in many ways a revolutionary development of the monolithic grid. All-welded steel diagonal grids have proved to have all the advantages of two-way concrete flat slab construction, with none of its disadvantages. The common practice in the design of the latter is to follow certain empirical regulations which place many limitations on the layout of panels in plan. The grids under consideration are entirely free from these restrictive rules, and are more adaptable to practical requirements.

From the design point of view, the flat-slab construction in reinforced concrete is wasteful because of the many uncertainties of the empirical calculations. The welded steel diagonal grids on the other

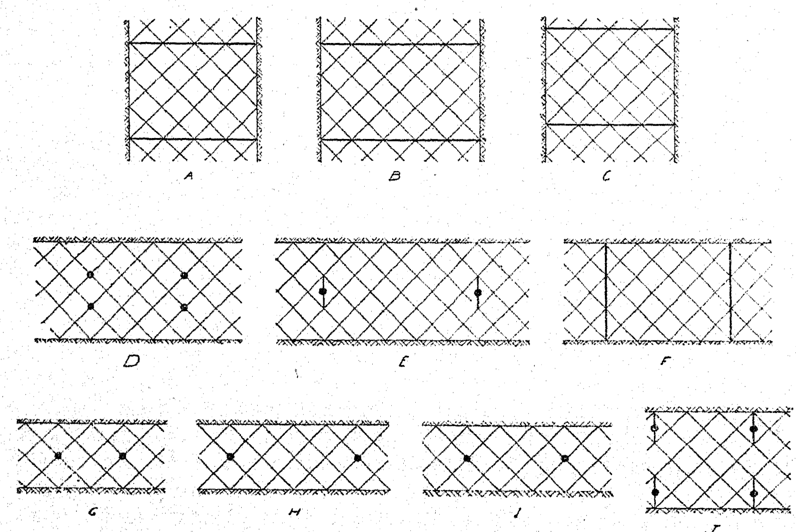


Fig. 10. Layouts for plane grids supported on two sides.

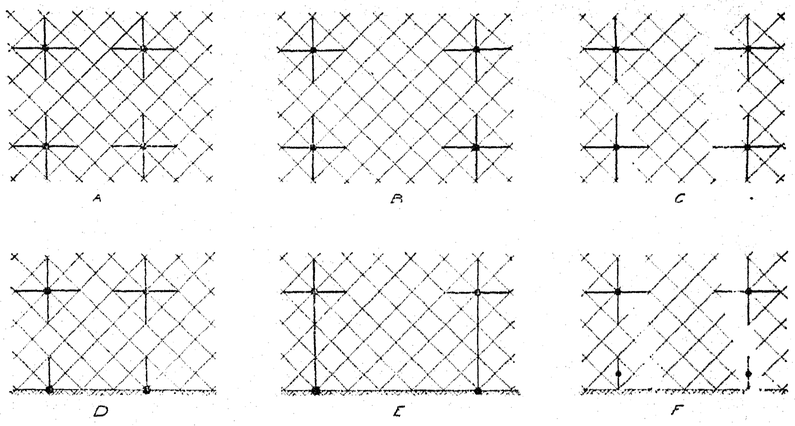


Fig. 11. Layouts for continuous plane grids.

hand, exploit the two-way reinforcement and drop panel ideas in the most economical manner, and all moments and shear forces are analyzed with great accuracy. It may be mentioned here that cracking round drop panels due to insufficient provision against shear effects is a common source of trouble in two-way slab design. In the steel diagonal grids these effects are known with greater accuracy, and no such trouble has so far been encountered.

Before passing on to the consideration of spatial grids, a mention must here be made of the other distinguishing properties of the grids under discussion:

(a) Due to the comparative smallness and regularity of the size of the sub-panels, the actual flooring or roofing material filling these sub-panels can always be made of very light construction with consequent economy. This factor is again reflected in the design of the grids, columns and foundations, which are all much lighter than those in orthodox design.

(b) The two-way system of diagonal grid beams form an ideal roof and floor construction for earthquake-proof structures in which the floor and roof elements are called upon to transmit horizontal forces. The grids under consideration provide many paths for these forces to follow, and in fact tend to reduce these very forces which are proportional to the dead weight of the building itself, because of its all-around lightness.

(c) For the reasons mentioned above, two-way monolithic grids would form a suitable flooring system in tall multi-story buildings which are subject to wind forces.

(d) By reason of their net-like properties diagonal grids form an ideal construction to withstand aerial bomb attacks. Slab panels are comparatively smaller in area, and are therefore better suited to resist such attacks. The grid beams, too, are so rigidly connected together that even if some of them are cut, the structure would not collapse although somewhat weakened.

Spatial Grids.—As in the case of plane grids for floors, the application of folded or curved grids can embrace almost any size or shape of spatial roof structure. A single pitch roof with a longitudinal central ridge member has already been described in detail. The logical develop-

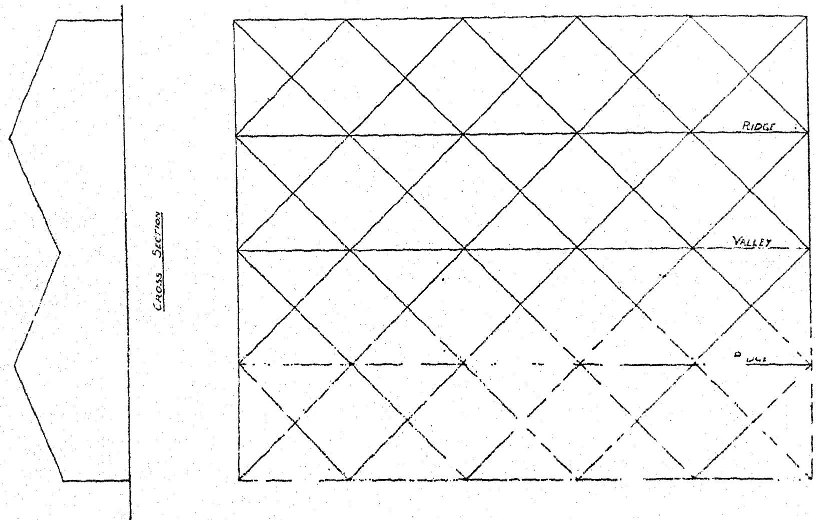


Fig. 12. Multiple ridge and valley roof—cross section and plan.

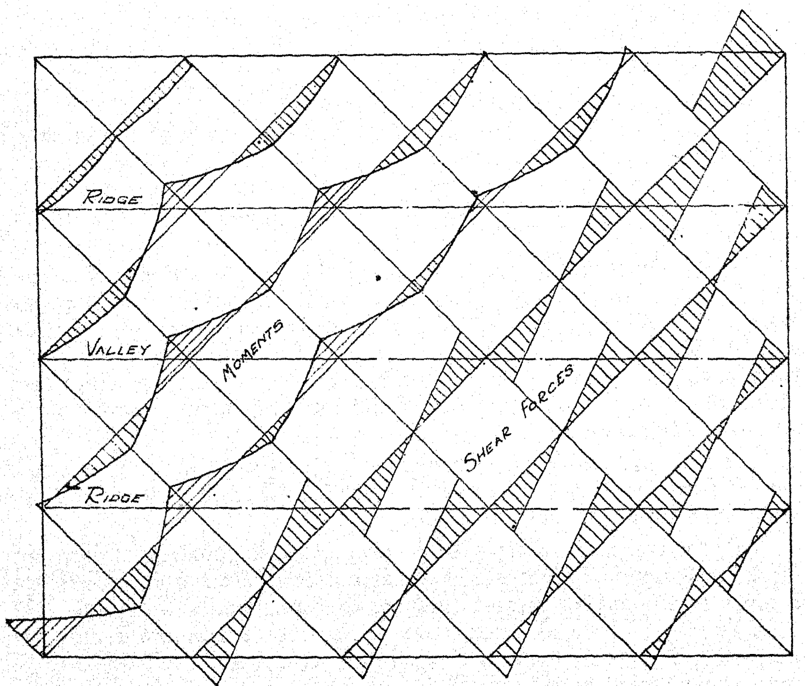


Fig. 13. Moments and shear forces on multiple ridge and valley roof.

ment of this is the multiple ridge and valley type of construction obtained by the folding of a plane grid—the fold lines coinciding with ridges and valleys—into any desired number of folds.

As will be easily understood, this opens up a field of application almost without any limit, as in the layout of the grids even greater freedom can be exercised. The shorter side of the building in plan can now be divided into 2, 3, 4 or 5 equal parts, and the longer side can, without any difficulty, be extended indefinitely. That this can be done would seem, at first impracticable, but a reference to Figs. 12, 13, 14 and 15 will prove that this is perfectly feasible. The effect of folding is to stiffen up the monolithic plane grid along ridge and valley lines, and the "corner action" mentioned before does not play such an important part. This removes many of the restrictions on the grid layout, and makes it possible to span distances up to 300 feet in the shorter direction (parallel to ridge and valley lines) and almost unlimited distances in the other direction.

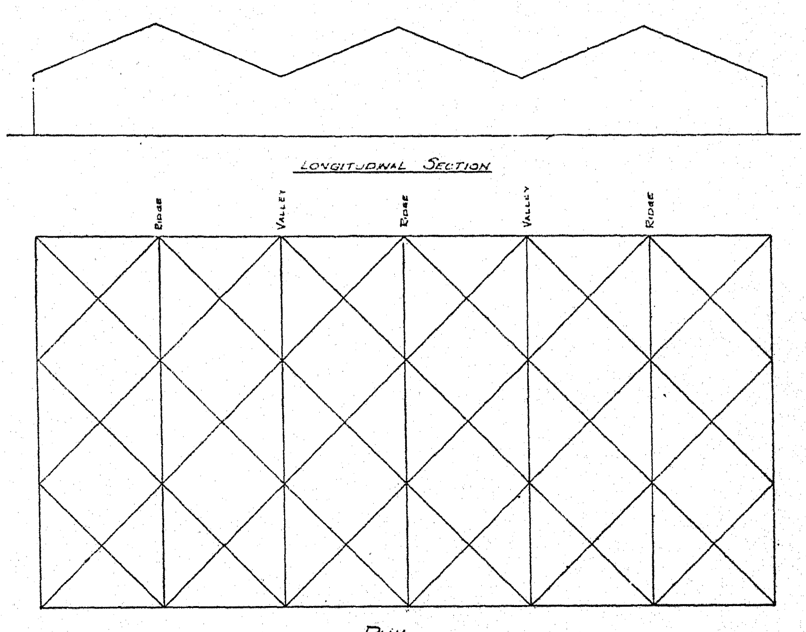


Fig. 14. Multiple ridge and valley roof—longitudinal section.

It is difficult to exaggerate the significance of the above statement for modern requirements arising out of the developments of methods of transportation, as also industrial manufacturing processes call for economical structures providing large unobstructed spaces. The present day tendency is towards the elimination of internal supports, and is limited only by considerations of economy. The monolithic spatial grids bring the fulfillment of this demand for large spans within bounds of practical economy, as available materials can now be utilized with maximum advantage.

A further reference to Fig. 13 which illustrates the incidence of moments and shear forces on the grid beams, will clarify the statements made above. The maximum moments in general occur at ridge and valley lines, and their magnitude is but a fraction of those occurring on a plane grid of the same size and layout. The shear forces too are not allowed to accumulate from the centre of the bay to the points of support, as they are taken up in the members as direct forces, at internal ridge and valley nodes. It is, however, found in practice that the major proportion (about 80%) of the maximum stresses occurring in individual grid beams is caused by bending, the remainder being due to direct forces.

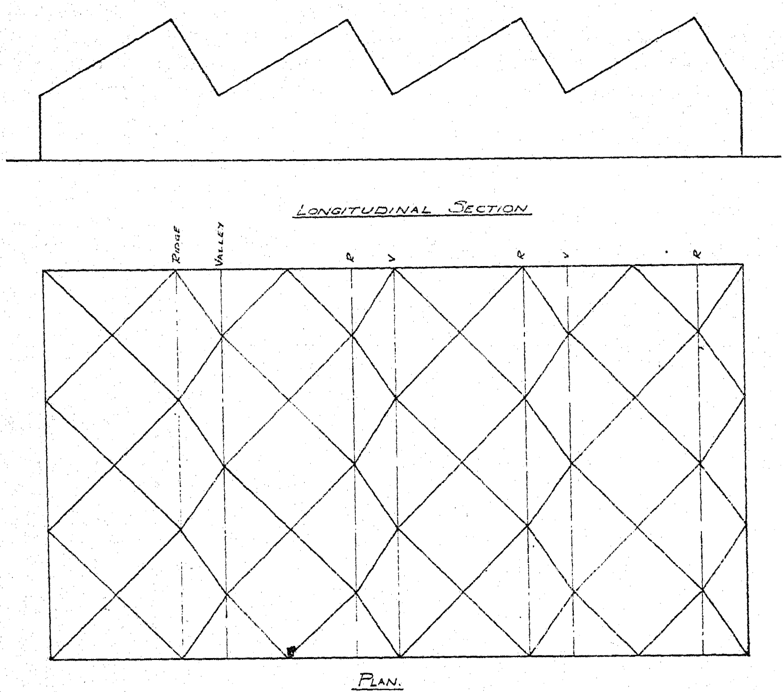


Fig. 15. Multiple north-light grid.

As a variation of the multiple ridge and valley type of spatial grids, we can now consider north-light or saw-tooth types of structures, which are favoured by many architects and engineers to obtain better lighting conditions inside the building. Fig. 15 illustrates a typical structure of this type which behaves, substantially, in a manner similar to that of the multiple ridge and valley spatial grids having equal slopes.

The folding principle can further be extended to curved roofs, which, although perhaps more pleasing in appearance, impose certain

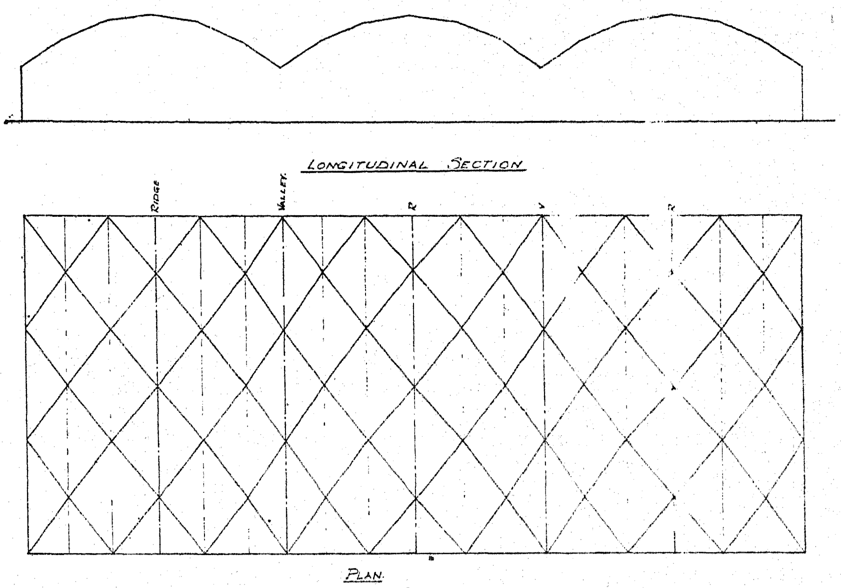


Fig. 16. Multiple arch grid.

limitations in the choice of the roof covering material. An example of this type of structure is given in Fig. 16.

Another useful variation in the shape of spatial grids (single or multiple bays) is the hipped type of roof preferred by some, for reasons of architectural treatment or of economy in gable wall construction. The monolithic grid can easily be adapted for such requirements, while maintaining all its inherent qualities of continuity and economy, as can be seen from Fig. 17.

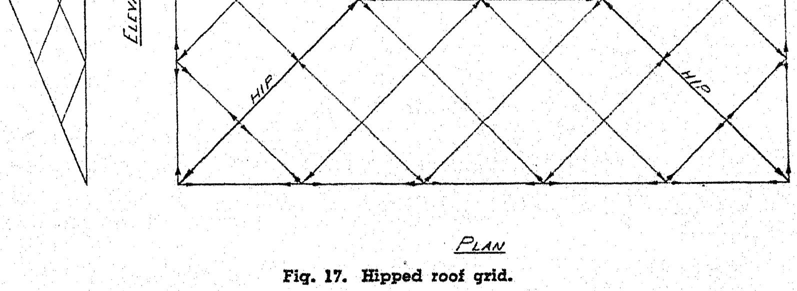


Fig. 17. Hipped roof grid.

In conclusion, we shall review briefly a few of the special advantages of the spatial grids under consideration:

(a) There is a complete absence of bracings, tie rods and other similar members below the planes of the roof structure. This, apart from the aesthetic advantages, improves the lighting and ventilation of the building.

(b) The sizes of members being substantially larger than those common in normal trusses, reduce the area of painting by as much as 40% in many cases. This leads to economy in first cost as well as subsequent maintenance cost, which is quite considerable in certain types of buildings such as chemical factories, laundries, etc.

(c) By the use of ordinary rolled steel sections available on the market, almost any spans ordinarily required can be covered economically. This eliminates the necessity of using built-up sections which are generally more expensive and require more time in fabrication and preparation before erection.

(d) The roof structure, because of the arrangement of members, is capable of resisting wind and other horizontal forces. This leads to an elimination of special wind bracing required in normal design.

(e) The spatial grids are better suited to withstand aerial attacks, which must be a serious consideration in the case of hangars, factories, garages, railway stations, etc., which usually expose a vast expanse of roof surface and constitute an easy target from the air.

(f) The storage space and cubic capacity of the structure are increased substantially because of the absence of columns, ties, bracings, etc. and goods can be stacked from floor level right up to the underside of the roof planes.

Principles of Detailing and Erection.—Two main factors govern the detailing of connections of members in engineering design—the forces and moments to be transmitted from one member to another at their connection and also the proposed method of erection of the structure. In the choice of sections for members themselves, additional factors are:

(a) Suitability for Welding.—This factor cannot be as extensively applied as those designing welded structures would wish. There are, in fact, but few rolled sections available on the market in this country* that are really designed for use in welded construction. The most notable is the tee section with a deep thin web and heavy flange; but this is of little use for beam work. The existing rolled steel joists and channels possess tapering flanges which render their preparation for butt welding unsatisfactory, and it is partly for this reason that the splice plates only are prepared and the joist flanges left square, in diagonal grid connections. The flanges of rolled steel joists and channels should preferably be rectangular in section.

(b) Considerations of Workmanship and General Handling.—This factor is applicable to all forms of steel construction, and does not warrant special remarks here.

(c) Relative Cost of Various Sections.—Generally, heavier sections

* England.

cost less per ton than lighter sections, and it will be seen that due regard has been taken of this fact as the grid beams are much heavier than sections commonly used in orthodox construction. Also, they are of constant section throughout, as are the purlins which also are light rolled steel joists.

In designing the members for the diagonal grid structures, and in detailing their connections, considerable advance has been made even in the last eighteen months.* Early in 1937 many details resembled closely their riveted prototypes. Each single structure has shown advancement over the previous one, as advantage has been taken of the experience gained.

In order to economize in space, only the most recent principles of detailing and erection adopted will now be described and not the history of their development, interesting though it is.

Regarding the actual types of welds used to connect members, these are either butt welds or fillet welds. Wherever possible and practicable, the butt weld is employed, as it is generally the most economical weld for developing the strength of a plate or section and also presents direct stress flow between the parts connected, obviating stress concentrations. At the ends of grid members the stress often reaches the permissible working stress for the material, and at these points the butt weld is now standard.

The latest regulations on structural welding in Great Britain permit the butt weld to develop the full strength of the sections connected, providing the reinforcement of the butt weld equals 10% of the plate thickness.

Fillet welds are employed where plates are detailed to overlap and to meet at right angles, and these are designed to the permissible stresses of the British Standard Specification No. 538, viz. 5 tons/square inch in longitudinal shear and 6 tons/square inch in transverse shear, acting on the throat area of a mitre section fillet weld, using electrodes which accord to this same specification.

Choice of Section of Members.—The layout of a typical diagonal grid structure is given in Fig. 18 with each member named as described below. It is seen that the spatial structure as used for roofs is very similar to the flat structure as used for floors, but with the addition of purlins, gable ties and ridge and valley booms. The eaves and gable edge members are in reality the ordinary edge members of the flat grids.

Grid Beams.—It has already been shown that in the flat diagonal grids, bending moments and shear forces act in the grid edge beams. In the spatial structures, by virtue of the girder action of the sloping planes, direct forces are also induced in the members.

The bending moments and shear forces in the grid beams are normal to the plane of the grid, whether it is flat, as in the case of a floor, or sloping, as in the case of a roof. The rolled steel joist is the most suitable and economical section to withstand these forces and is placed

* At time paper was written.

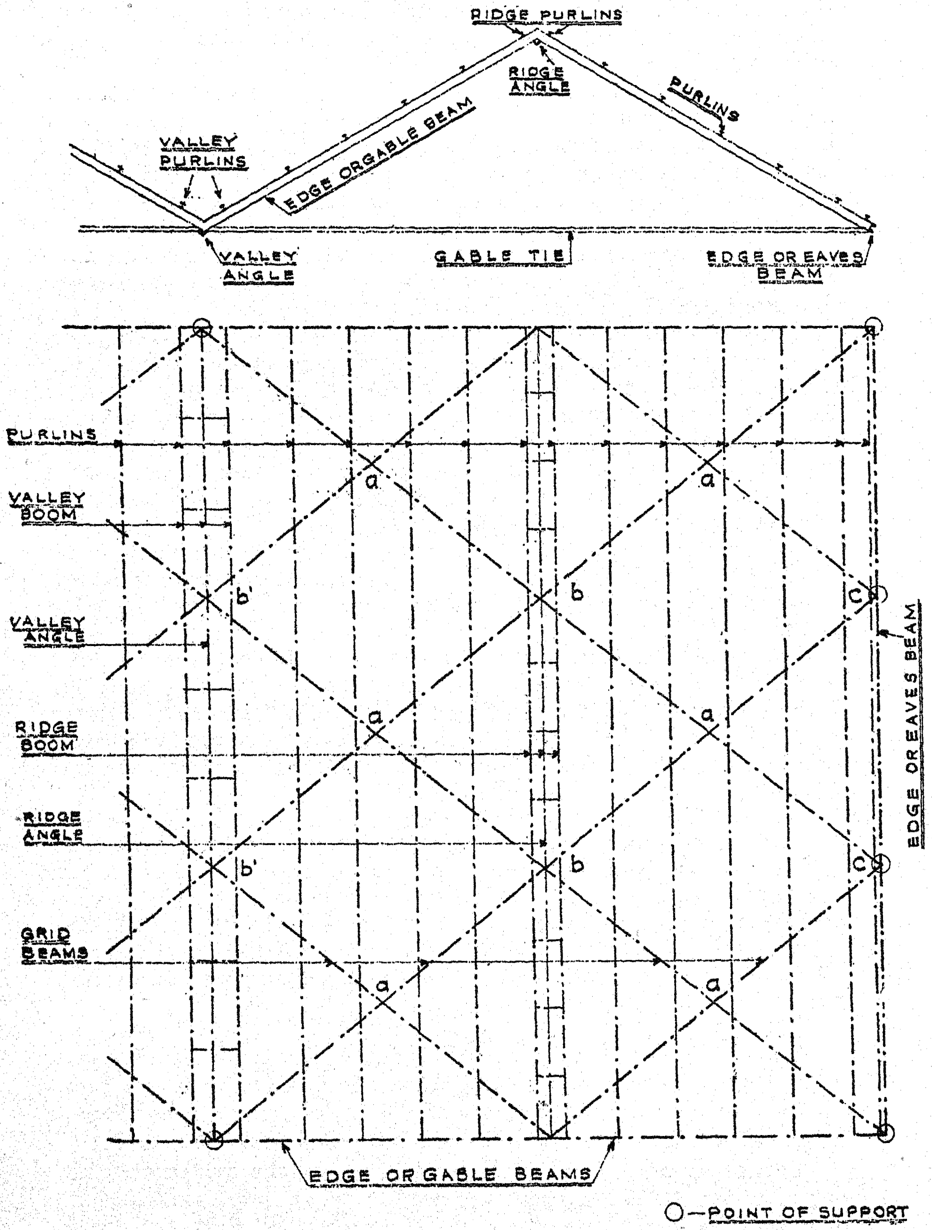


Fig. 18. Layout of typical diagonal grid structure.

with its web perpendicular, and with its flanges parallel to the plane of the grid.

Generally, the moments change from +ve to —ve between the centre of a grid plane and the ridge or valley lines; the maximum moments occur on these lines. The distance over which the moments of either sign act as in normal structures is greater for the +ve than for the —ve. Thus, for the greater proportion of the lengths of the grid beams the top flanges are in compression. It is necessary that these should be given lateral support against buckling which is provided in the case of flat grids by the flooring material—usually reinforced concrete slabs—and in the case of the spatial grids by the roof purlins, which are welded to them.

The direct forces in the spatial grids induced in the grid beams due to girder action, are added algebraically to those due to bending and are usually of a small proportion compared to the latter.

Edge Beams.—In both flat and spatial grids, rolled steel channels are used as edge members principally for the ease of connection to the grid beams. The edge members become eaves and gable members in the spatial grids. Again, we have moment and shear forces in the edge members plus direct tension and compression in the case of the spatial grids. Rolled steel channels are capable of carrying these quite economically and are turned with their flat back inwards to facilitate the detailing of the connection to the grid beams.

Usually support of the grid is arranged at the edge node points, but architectural considerations may require supports at intermediate points. In this case, it is often necessary to reinforce the flanges of the edge beams by welding additional plates to them.

The eaves channels are always in direct tension, but the gable channels are in compression. Lateral support against buckling in the direction of the weak axis of the gable channels is provided by the purlins. For gable spans above 40 feet, it is necessary to introduce web framing in the gable to form a support at the grid node when a grid with three divisions per gable is used, (See Fig. 6), and also to support the gable tie vertically.

Gable Ties.—The gable tie in the spatial grid serves to prevent spreading of the grid planes, and acts in tension. It is usually a channel section as it can then be fillet welded back to back to the gable channels.

Ridge and Valley Booms or Chords.—Other main members in the spatial grids are the ridge and valley booms or chords. It is convenient to use the two top or bottom purlins in the slopes together with angles introduced under the grid beams at the ridges and valleys respectively, braced together to form deep composite triangular members. This is an advantage in the case of the ridge boom and withstands the compression force adequately, as it possesses a large radius of gyration, (See Fig. 19).

As in ordinary girders, load is induced into the booms by increments at the panel points. In small and medium size spans up to about 100 feet, (measured in length of ridge or valley), the standard purlins as

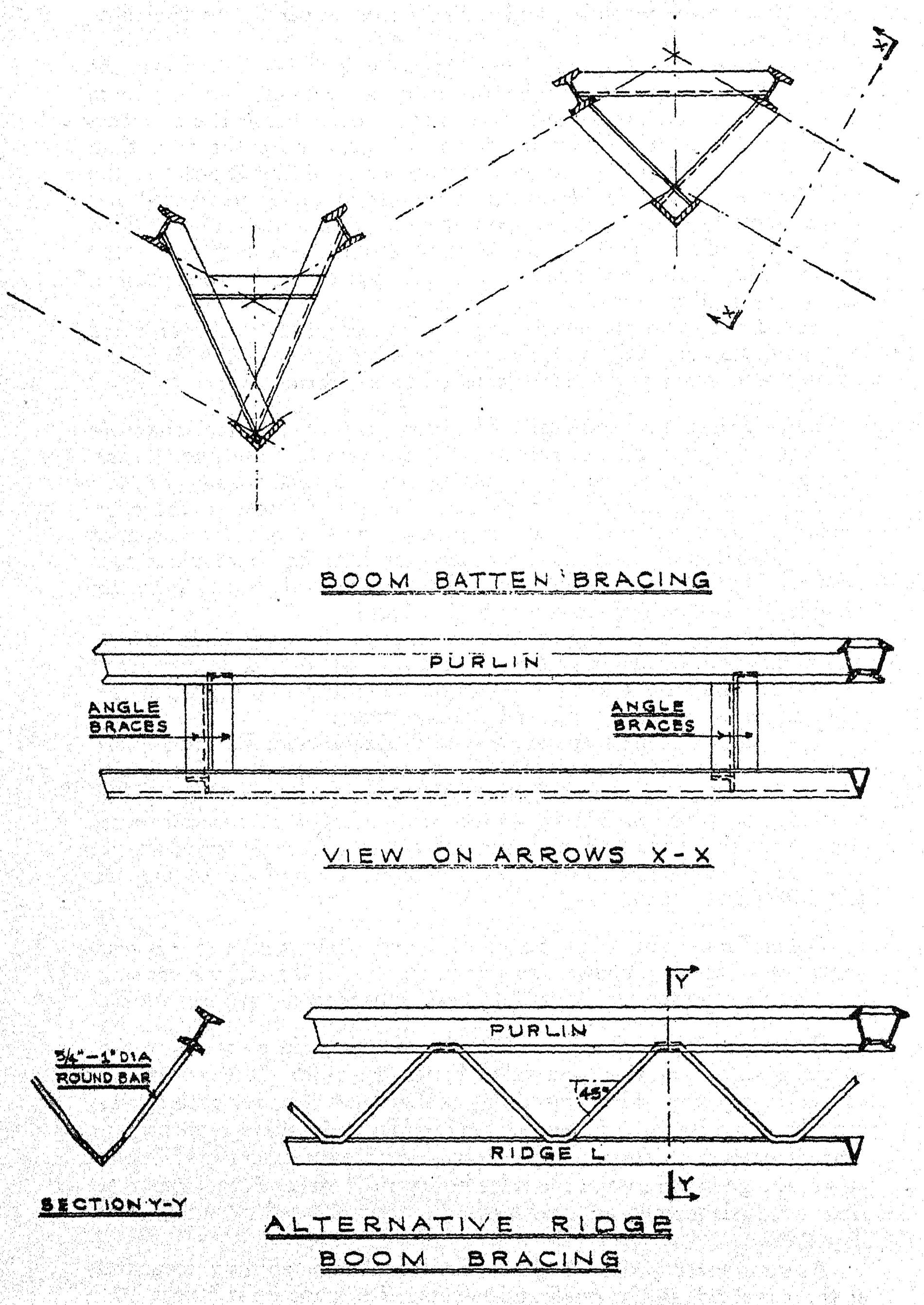


Fig. 19. Boom batten and alternative ridge boom bracing.

used throughout the roof, together with the angle mentioned above, are sufficient to withstand the boom load at the centre of the span because of the large depth of the girder or grid plane. With longer spans or with wider gables, it is necessary to increase the sectional area of the boom by employing heavier or additional sections, of equal depth to the purlins.

The bracing of the three members to form a composite member is carried out on the battening principle by light angles, or on the lacing principle by a bent continuous rod as shown in Fig. 19. In the ridge or compression boom, the centres of the battening angles are such that the slenderness ratios of each of the members is not exceeded for the stress that they are required to carry. For the tension booms the centres are greater, as the bracing angles are merely maintaining the relative positions of the individual members.

Roof Purlins.—To carry the roof covering, purlins are spaced at suitable centres and run longitudinally along the roof planes. To withstand bending moment, rolled steel joists are used and generally the smallest or next smallest structural size is suitable. They are butt welded into continuous lengths for the full length of the roof, and may thus be designed as fully continuous beams.

By virtue of the arrangement of the grid beams, the purlin spans vary up to a limit equal to the panel length, or the distance between consecutive nodes. It is not, however, practicable to vary their size to suit the individual spans and they are of uniform section throughout. The splices are arranged over the grid beams for convenience of assembly and erection, and connection to the latter is made by short fillet welds of small leg length on both sides of the purlin lower flange.

Supporting Stanchions.—Finally, the support of the structure may be effected on a brick wall or continuous concrete beam made under the edge channels, or by stanchions placed at the edge nodes. Stanchions normally consist of plain or plated rolled steel joists, but on large structures composite sections such as two channels welded toe to toe, or battened together, are very efficient.

Except in very large structures, it is economical to transmit horizontal wind force from the structure to the ground by virtue of the resistance of the stanchions to bending, instead of by the normal cross-bracing arrangement. As each roof is a monoferric structure, all the stanchions resist the wind load according to their stiffnesses. They are then rigidly connected to the roof structure and may be designed as fixed at the base if desired. Advantage is taken of the savings obtainable by welding the stanchion base details.

To conclude these remarks on choice of sections for members, it should be stated that no allowance is made for holes in them, as these are not required as for riveted structures. Thus, the sections are all net. Where it is advantageous to use temporary assembly and erection bolts to aid location of members, they are arranged to pass through the member webs.

It is sometimes economical to use a lighter section grid beam than would resist the higher bending moments, and to plate their flanges

where necessary. Generally, however, a constant section is chosen so that plating of grid beams is eliminated.

Influence of Shop Costs, Handling Charges, etc. on Detailing of Connections.—In Great Britain, the welding of structural steelwork has not yet reached that stage where there is sufficient quantity to keep the whole of a fabricating shop working full time. Development has been gradual, and the welding shop is almost invariably relegated to a dark corner of the plant. Nevertheless, it is made to carry the overhead costs that the riveted structures carry, in spite of the fact that its real overhead costs are probably only 25% of those of the riveted and bolted structures.

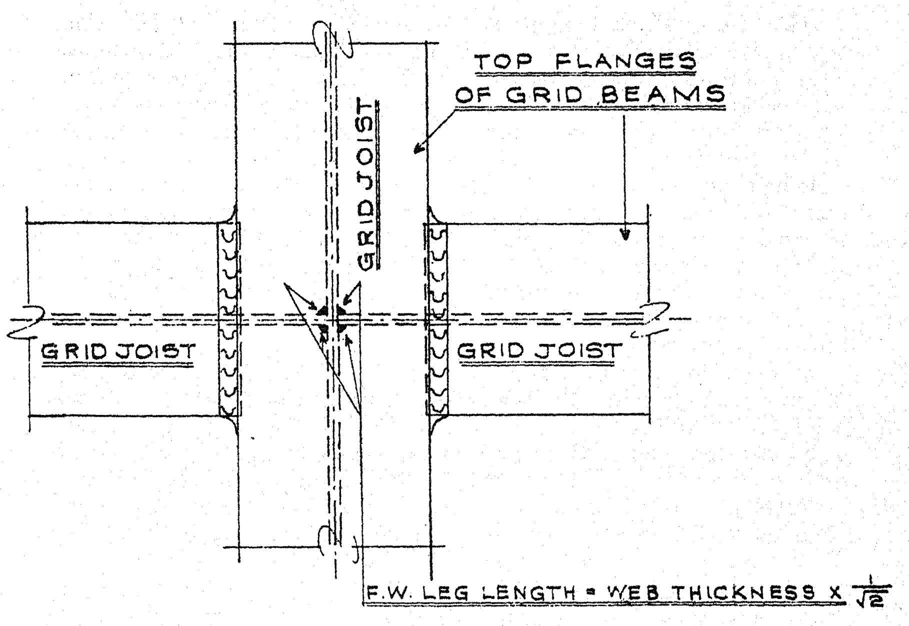
As in Australia, for example, owing to the heavy cost of shop fabricated work it becomes cheaper to detail members and connections so that all the operations of preparation etc. may be carried out in the field instead of in the shops. Owing to the facilities available, it is more convenient to fabricate plate girders and heavy compound beams and stanchions in the shop, but in the case where sections are only cut to length, possibly prepared for butt welding at their ends, and with a few holes required for erection bolts, it becomes cheaper to site-fabricate. In the latter case holes for location and erection purposes may be drilled by portable electric drills driven from the welding plant or supply.

The aim in detailing diagonal grid connections has been to reduce the amount of work to be done on the rolled sections to a minimum, and to make any preparations necessary on the splicing plates. For instance, the grid beams when their flanges do not exceed $\frac{1}{2}''$ in thickness are, for butt welds, cut dead square at their ends, notched at the centre of their length and drilled with two holes in the web at each end for location purposes. These three operations may be efficiently carried out in the field, greatly reducing the cost of the work.

Member Connection Details.—Referring to Fig. 18, it is seen that the main details common to both flat and spatial grids are the grid beam plane intersections, and the grid beam to edge beam connections. Further connections in the spatial grids are the ridge and valley line intersections of the grid beams, and other connections also which may be met in ordinary welded structural work are the gable tie to gable edge beams, gable web framing, purlin to grid beam and splices of the component lengths of certain members. The edge beam details are usually arranged for connecting to stanchions or as plain seats on brick or reinforced concrete walls.

The objective has been to standardize each connection, whether for flat grids or for arched north-light or ordinary pitched grids. Thus, the ridge and valley line connections for each of the latter cases vary only in the angle between the two slopes or grid planes connected. This standardization is especially economical in drawing office costs, as connection detail drawings can be produced very rapidly, besides leading to fabrication and erection savings.

All grid beam flanges are spliced with butt welds, as are most long members made up from stock lengths.



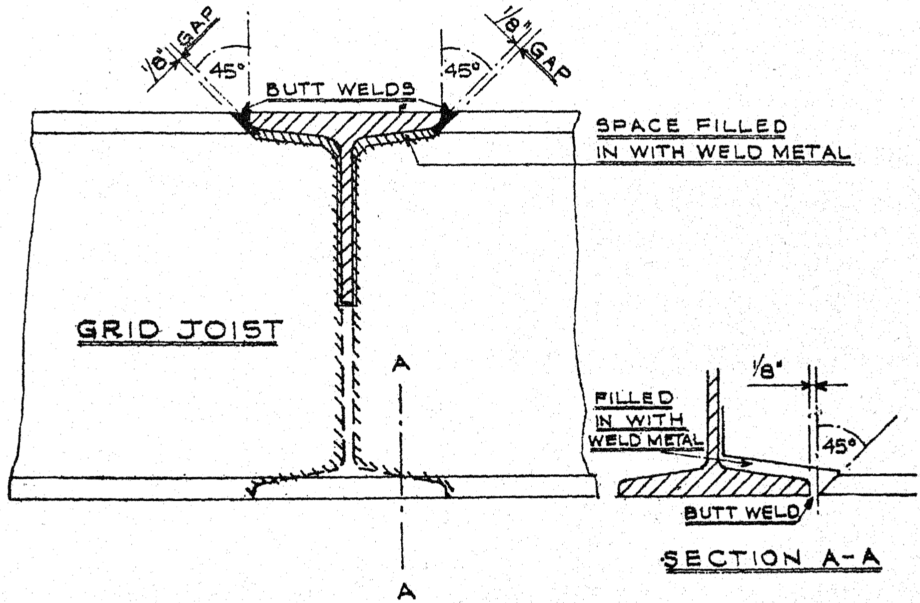


Fig. 20. Grid beam plane intersections and grid-beam to-edge-beam connections.

Grid Beam Plane Connections.—Describing each main connection separately, we shall deal first with the grid beam plane intersections. This is effected by half notching each rolled steel joist as shown in Fig. 20, one in the top half, and other in the bottom, so that they fit together in "eggbox" fashion and also are automatically located one relative to the other. Continuity of the notched flanges is obtained by butt welding them to the toes of the uncut flange passing transversely across them. The webs are notched to clear the radius at the roots and are fillet welded to the inside of the flanges of the other grid beam.

The preparation of the butt welds is also shown in Fig. 20. A 45° cut in the flange is made so that the gap for the butt weld equals 1/8″ minimum. The butt weld is completed with a sealing run on the undersides of the flanges.

A modified preparation is to continue the 45° cut into the web until the web notch is reached. This enables a continuous sealing run to be deposited for the full width of the flange. Tests have shown that this detail develops the full strength of the joists connected. The connection is completed by fillet welding the webs to develop the reaction between the two grid joists. Photographs of this plane intersection are given in Fig. 21, in which it is seen that the webs are cut to the profile of the flanges. The notching is performed rapidly and economically by oxy-acetylene or coal-gas cutting.

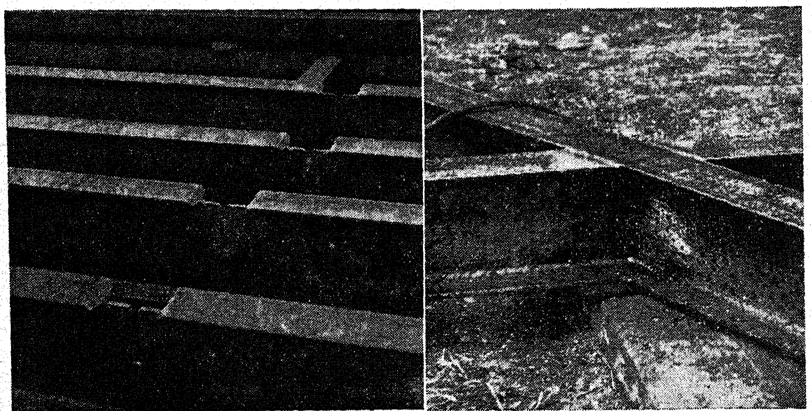


Fig. 21. Half-notching, (left), and welded connection of grid beam plane intersections.

Ridge and Valley Connection.—As the grid beam to edge beam connection is developed from the detail of the grid beam ridge and valley line connections of the spatial grids, we shall describe the latter first.

The principle of the ridge and valley connection is to transmit the flange loads and web loads simply and adequately, and to provide balance for the change of direction of the flange loads at the bends in the flange splice plates. In these connections, four rolled steel joists meet in the form of a pyramid or reversed pyramid, but the joists are arranged with the flanges of each pair in the grid slopes or opposite slopes of the pyramids.

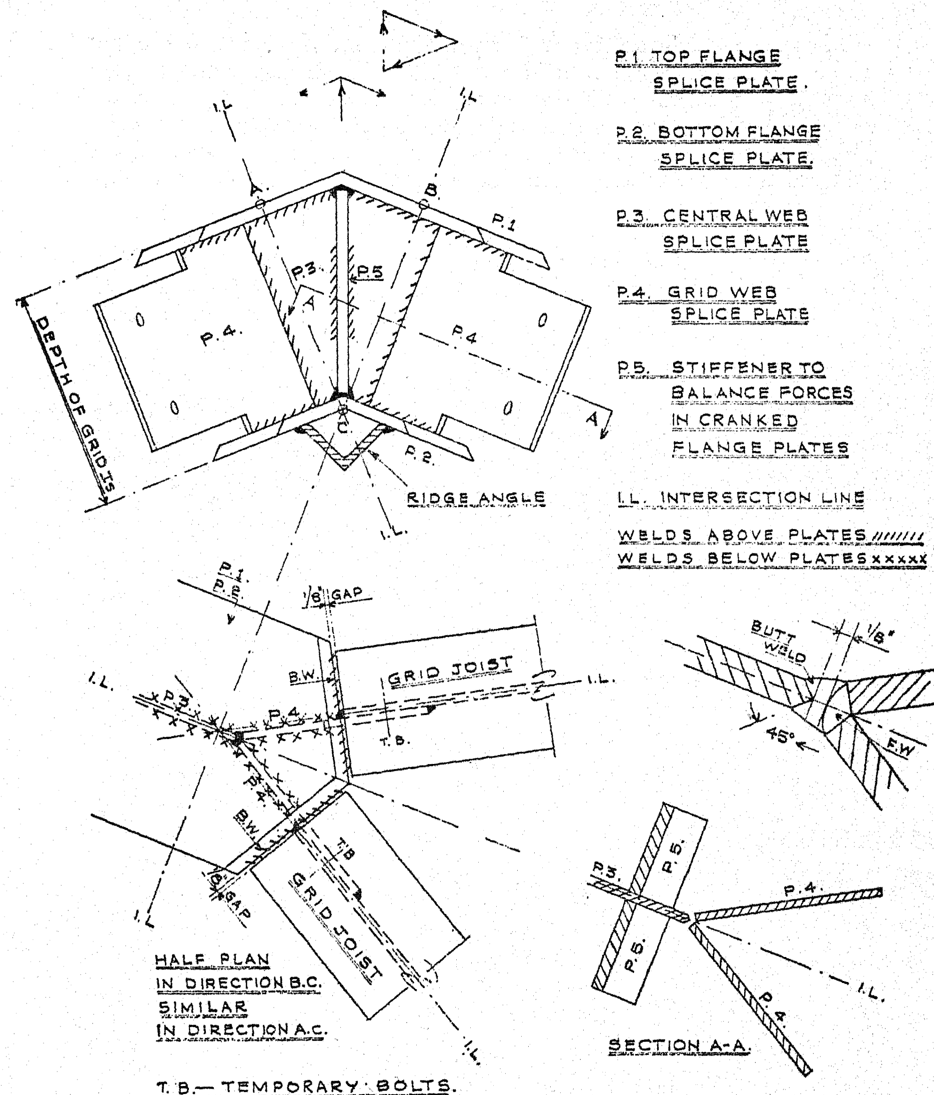


Fig. 22. Grid beam ridge connection box.

Figs. 22, 23 and 24 illustrate the manner in which these connections are made. A ridge or valley node box is fabricated from flat plates connected together by fillet welds, and is of such shape that the grid joists need only be cut dead square at their ends. Box, (Fig. 22), is that used for pitched roof ridges, and box, (Fig. 23), is that used for north-light roofs. Valley boxes are identical with the ridge boxes, but are reversed. In arched roofs the detail is very similar to that of the ordinary pitched roofs, except that the change of angle between adjacent slopes is very small.

Referring to Figs. 22 and 23, plates P1 and P2 splice the upper and lower flanges of the four intersecting grid joists respectively. They may be bent on the ridge line or may be made each from two plates butt welded together. The latter operation may be carried out completely in the field, whereas, the former requires the passage of the material through the shops and also is not as accurate in workmanship.

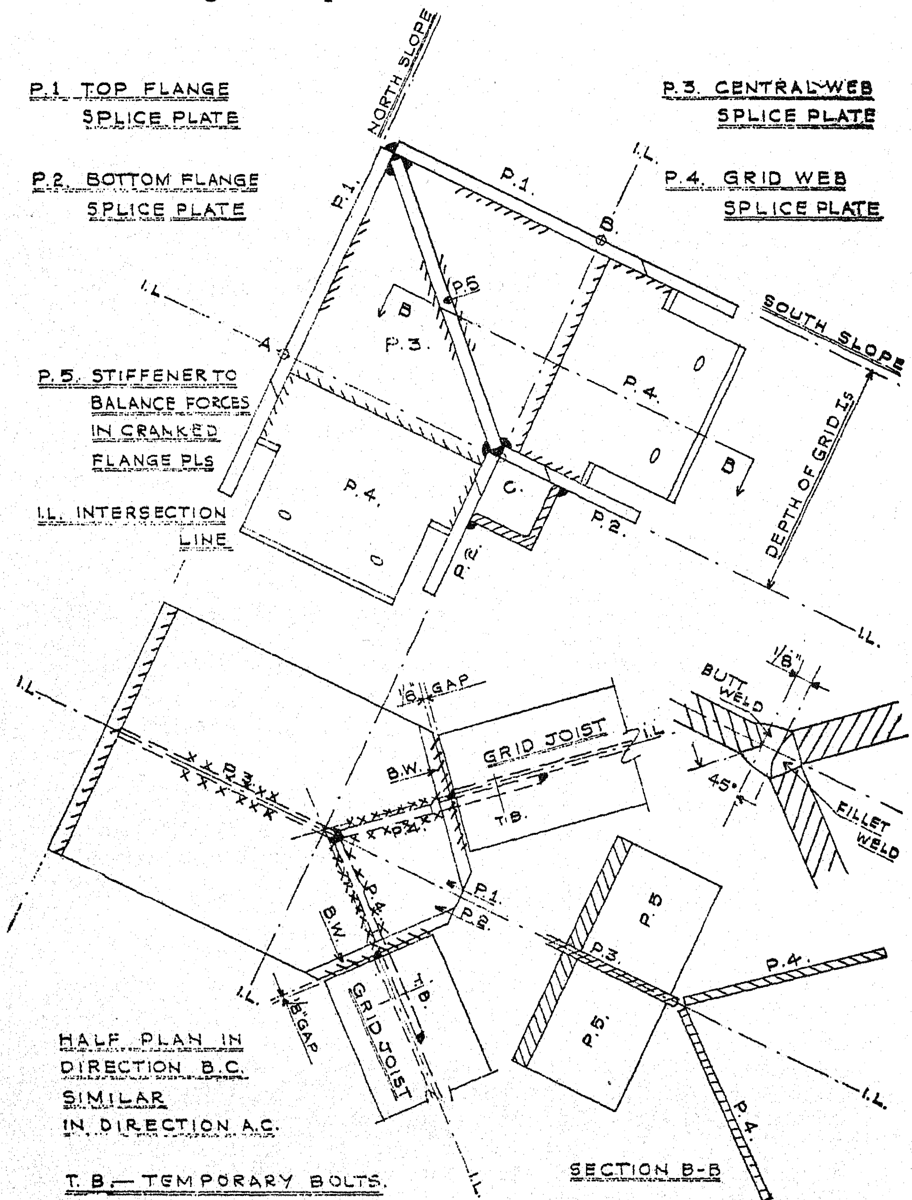


Fig. 23. Ridge or valley node box for north-light roofs.

These plates are flush with the grid joist flanges and are butt welded to them. When the flanges of the grid joists do not exceed ½″ mean thickness, the splice plates only are bevelled for the butt weld. The details of the butt weld are: single Vee preparation, angle of preparation 45°, gap ⅛″ minimum, and both top and bottom Vees to be welded in the downhand position, with one sealing run underneath.

The central web splice plate P3 varies in profile according to the type of roof, and equals in thickness $\sqrt{2}$ x thickness of webs of the grid joists, as it meets two pairs at approximately 45°. It is butt welded to plates P4 with double-Vee preparation, as shown in Figs. 22 and 23.

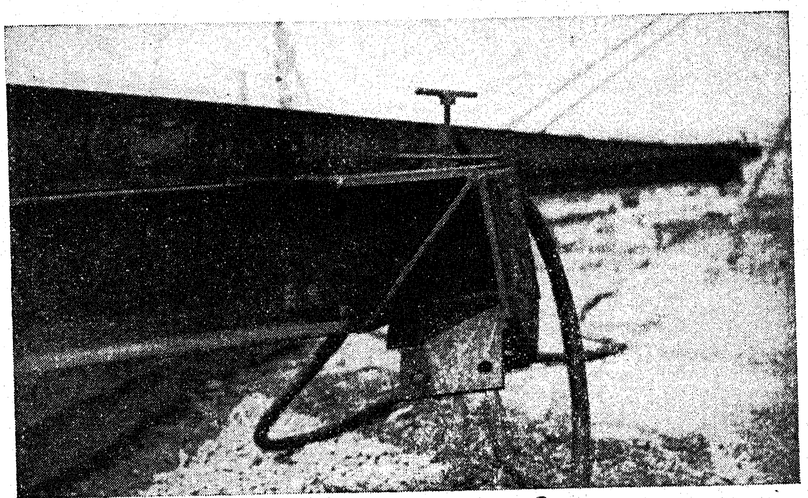


Fig. 24. Ridge or valley node box fabricated from flat plates.

Plates P4 are all identical in shape and splice the grid joist webs to the common centre web splice plate P3. As shown they are lapped over the grid joist webs in order that temporary erection bolts may be used. It is technically better, however, to butt weld them direct to the grid joist webs, positioning with temporary erection cleats, which results in a much neater connection. They are notched in order to allow clearance for the butt welding of the flanges to be carried out without interference. The notch is made commencing about 1″ back from the web of the grid joist and is 1″ deep, allowing the welder to deposit continuous runs across the width of the grid joist flanges.

Plates P5 serve as stiffeners to the web plates P3, and also connect the top and bottom flange splice plate P1 and P2 at the bends, thus balancing their resultant forces or in other words completing the triangle of forces at these points. With plate P1 in tension and P2 in compression, plates P5 are in compression, and are anchored to the web plate P3 with short lengths of ¼″ fillet weld.

Grid Beam to Edge Beam Connection.—Figs. 25, 26 and 27 show details of the standard grid beam to edge beam connection. This

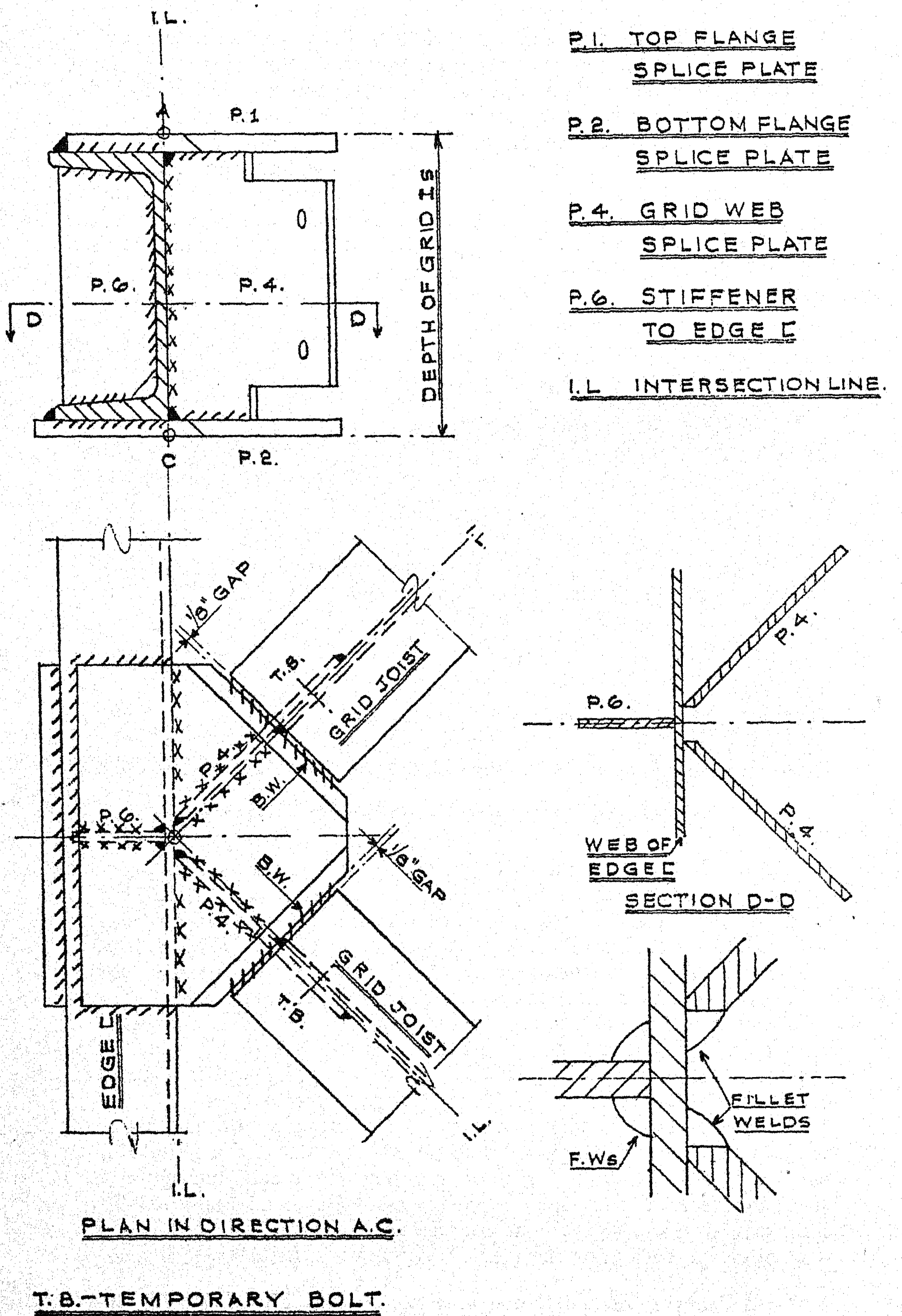


Fig. 25. Grid beam to edge beam connection.

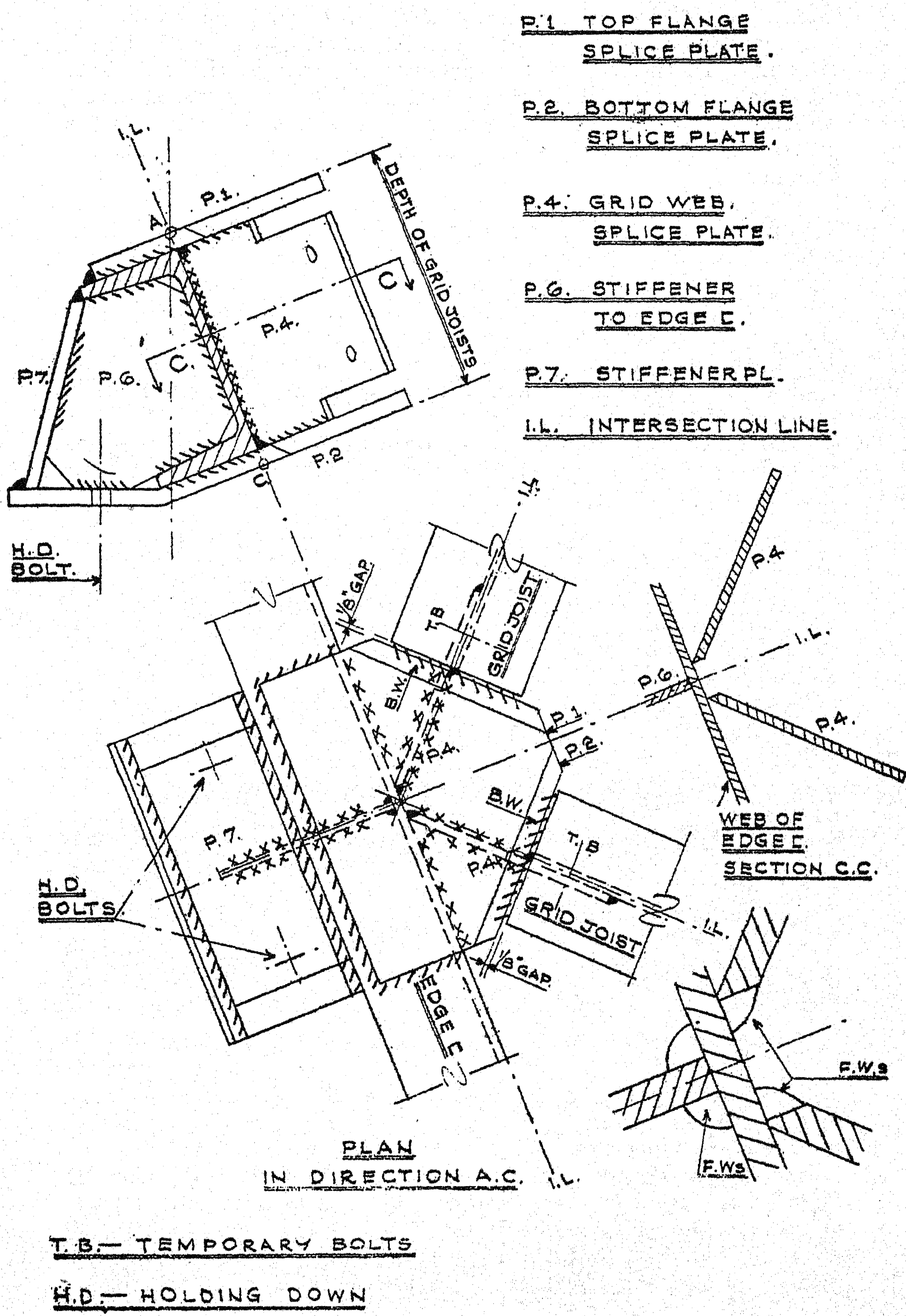


Fig. 26. Details of grid beam to edge beam connection in spatial grid.

connection follows exactly the principle of the ridge and valley line connections, and applies to both flat and spatial grids. It will be seen that plates P1 and P2 and plates P4 connect to the grid joists as for the ridge and valley details, and are each fillet welded to the edge beam which is a rolled steel channel section. These fillet welds are designed to transmit the forces passing between the grid joists and the edge channel.

The edge channel is turned with its toes away from the grid joists, but its back is placed on the meeting of the intersection lines of the latter. Normally, these channels are made 1″ shallower in depth than that of the grid joists, as the forces acting on them do not warrant their being of equal depth. Plates P1 and P2 are, therefore, made to overlap the flanges, P1 being ½″ short of the toe and P2 passes the toe by ½″ to enable downhand fillet welds to be made in both cases. Plates P4 are fillet welded to the web of the edge channel and require to be bevelled for this purpose.

A further plate P6 is welded between the toes of the edge channel to stiffen the connection and to transmit web load to the channel flanges.

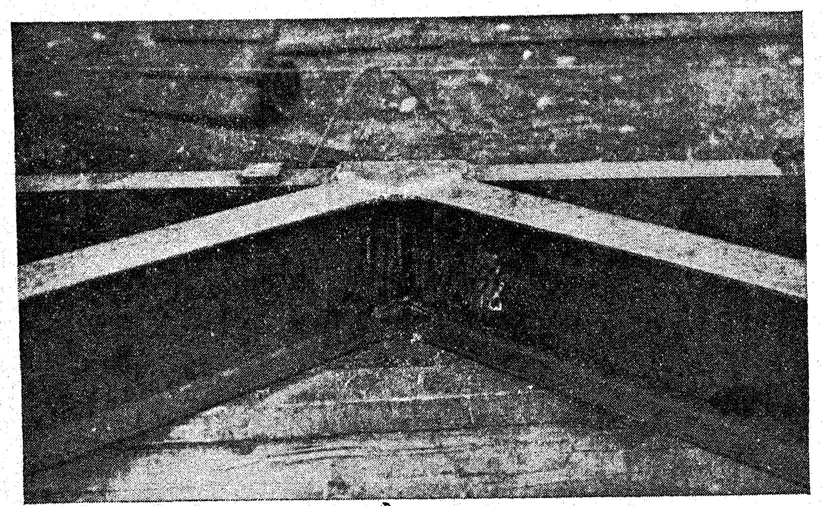


Fig. 27. Photo of arc welded grid beam to edge beam connection.

The spatial grid, Fig. 26, requires the edge channel to be tilted to the plane of the roof. A seat is made for the connection to the stanchion or supporting wall, by extending plate P2 and bending it horizontally outside the bottom flange toe of the edge channel. Plate P6 is altered in shape in order that it may connect to P2 and so transmit the grid reaction at that point to the support. Plate P7 serves to stiffen plates P6 and P2. Plate P2 is holed for holding-down bolts or for temporary erection bolts to the cap plate of a stanchion.

Purlin to Grid Beam Connections.—Purlin connections to grid joists are very simple, (See Fig. 28). The fillet welds position the purlins

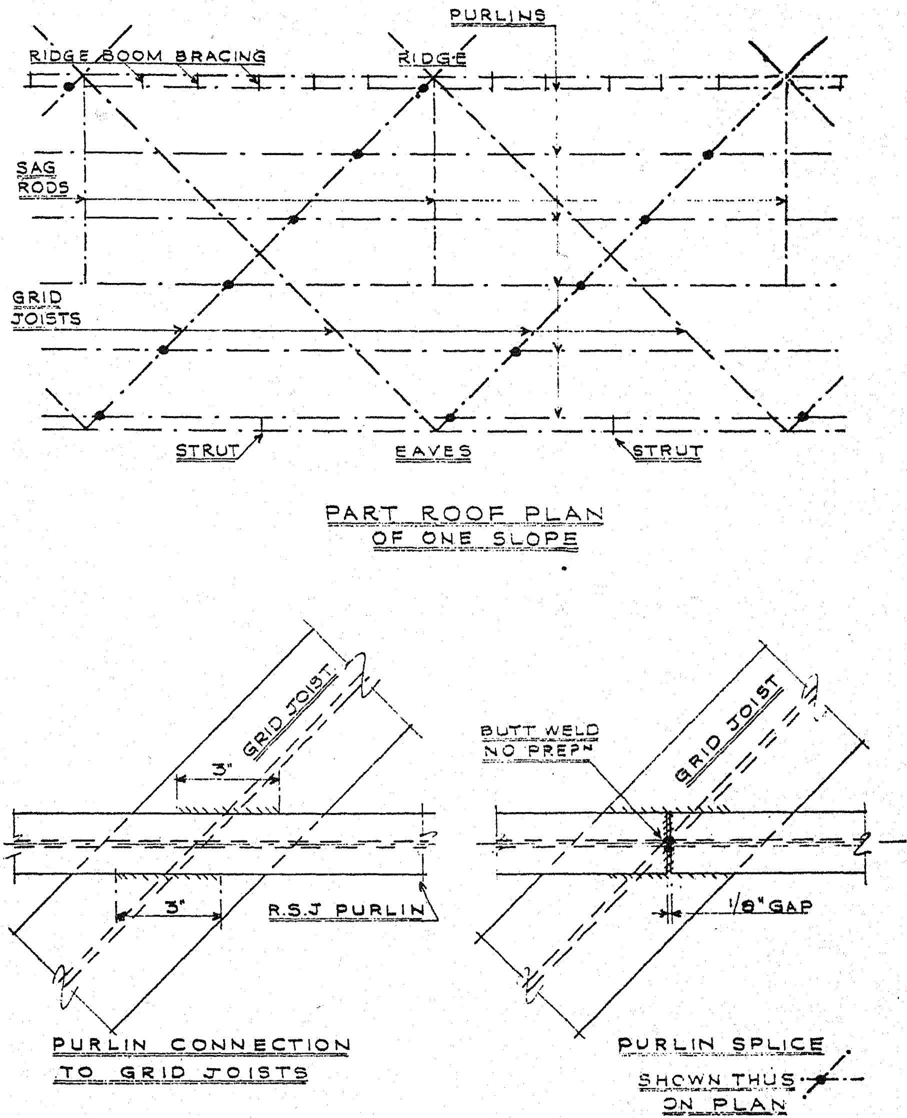


Fig. 28. Purlin to grid beam connection.

relative to the grid joists and for 4″ x 1¼″ x 5-lb. rolled steel joist purlins. 3″ of $\frac{3}{16}$″ fillet weld, either side of the purlin bottom flange, is ample. Where the purlins form part of the ridge or valley booms, these fillet welds must be designed to transmit the increment of load passing into the purlin at each grid beam, or panel point. They then become longitudinal shear fillet welds.

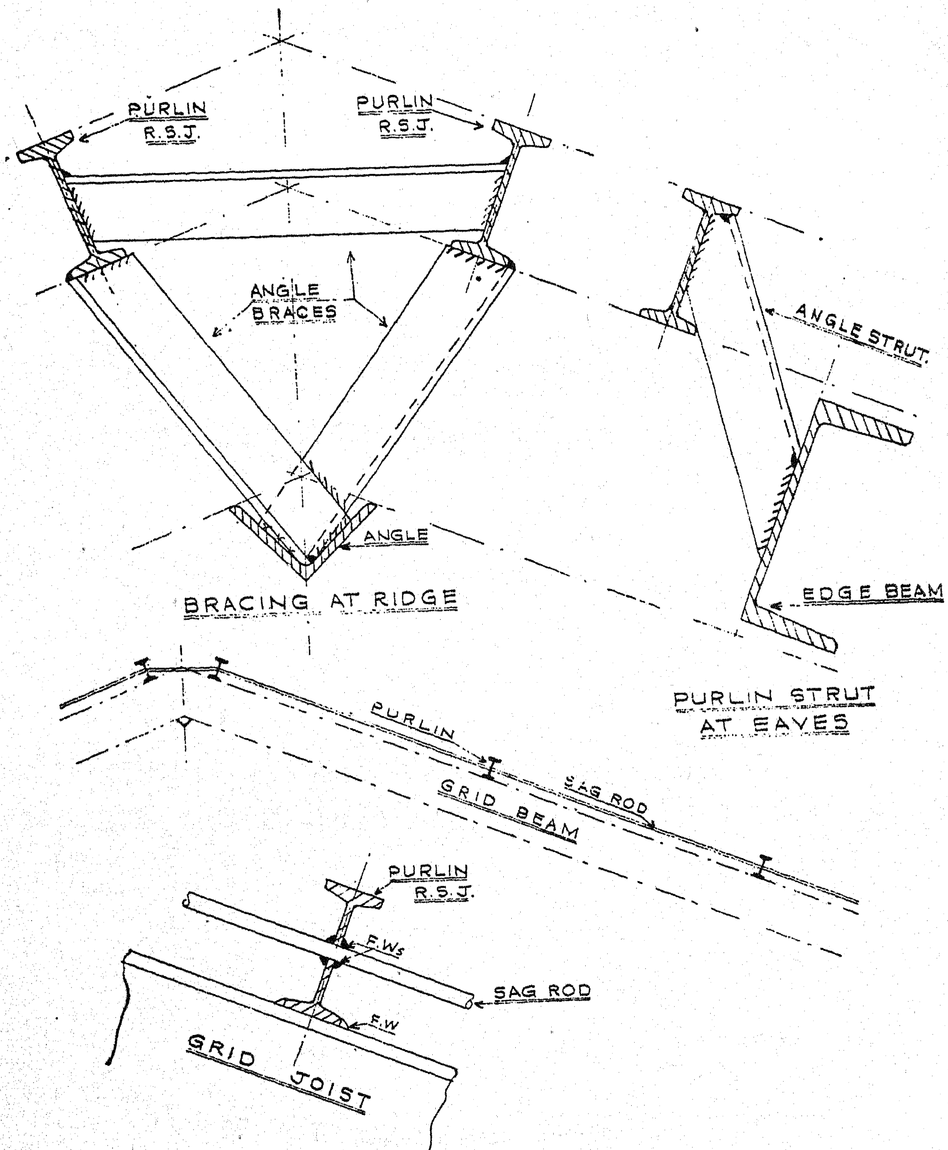


Fig. 29. Details of rods welded to purlins in the plane of the roof to prevent sag.

Purlin Sag Rods.—To prevent sag of the purlins in the plane of the roof, sag rods are employed to give them lateral support. Instead of the short bolted sag rods, as used in orthodox construction, they are made in as long lengths as necessary, pass through the webs of the purlins and are lightly welded to them. They are quickly fitted and economical. See Fig. 29.

The lowest purlin in the eaves is supported at midlength with a short angle strut welded to it and to the edge channel.

The remaining connections are very similar to those already described, and will not be dealt with in order to avoid repetition of description.

Erection.—As with the designing and detailing aspects of welded steelwork, it is necessary in order to reap all the advantages available, to consider erection apart from the practice that has developed in riveted work. It is hoped to show that this has been achieved in the case of the diagonal grid structure as built today.

Originally, the structures were erected piece small or nearly so, that is, the stanchions were first erected and plumbed. Then the eaves and gable edge channels, followed by the grid joists and finally the purlins and boom bracings were lifted into position individually and welded.

The great proportion of the welding was carried out in the air, with the welders perched on ladders, sitting astride members, or at the best standing on improvised scaffolding.

A considerable number of scaffolding poles was essential to maintain grid members in their correct vertical positions until the welding of the grid nodes and ridge and valley booms was complete.

It will be appreciated that these conditions are not likely to result in as satisfactory welding and erection as could be obtained were the work carried out under more ideal conditions for both welders and erectors. Considerable speeding up of the work was also desired and the authors believed that the method of erection now adopted does attain these ends.

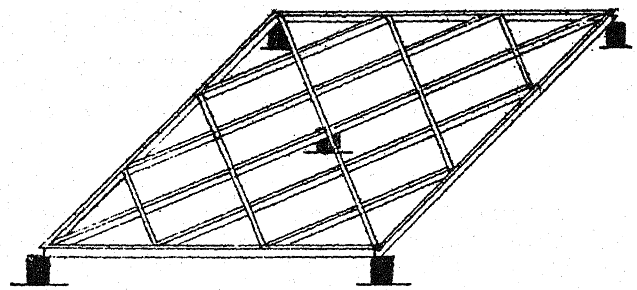
An important cause of delay was the scattered nature of the welding in small quantities at each connection. In order to proceed from one connection to another, it was often necessary for the welders to climb up and down ladders, dragging their equipment with them. This was obviously wasteful, particularly in the case of the numerous purlin connections.

To eliminate delay, an attempt was made to increase the welding to be carried out under comparatively comfortable conditions, viz., at ground level.

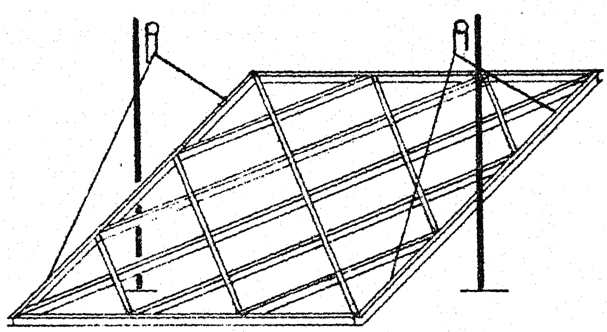
In the case of flat grids, the whole structure may be thus fabricated, and all that is then required is to lift it up to just above its final level, erect the stanchions and to bolt or weld it to them. This is shown diagrammatically in Fig. 30.

Erection of the spatial grid or roof is slightly more complicated. Each roof slope is assembled and welded complete on the ground with its eaves channels, gable channels, grid members and purlins on trestles at suitable working height for the welders, that is, about 2′—6″ above ground level. On the completion of the slope it is lifted into position on the stanchions and temporarily propped until the adjacent slope is similarly lifted, and the two are then welded together at the ridge. See Fig. 31.

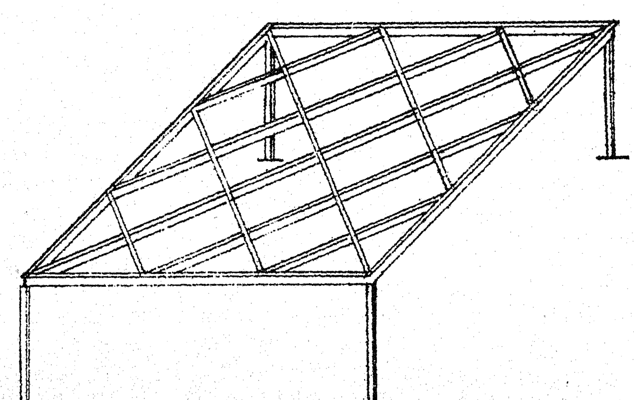
Thus, the erectors and welders work mainly at ground level, and considerable improvement results in the quality of the work. But a further improvement has been made, overcoming the difficulties of



1. FABRICATION OF FLAT GRID ON TRESTLES ON GROUND



2. LIFTING OF FLAT GRID, TO JUST ABOVE FINAL POSITION.



3. FLAT GRID IN POSITION ON STANCHIONS

Fig. 30. Diagrammatic sketch showing ground-fabrication and erection of flat grid.

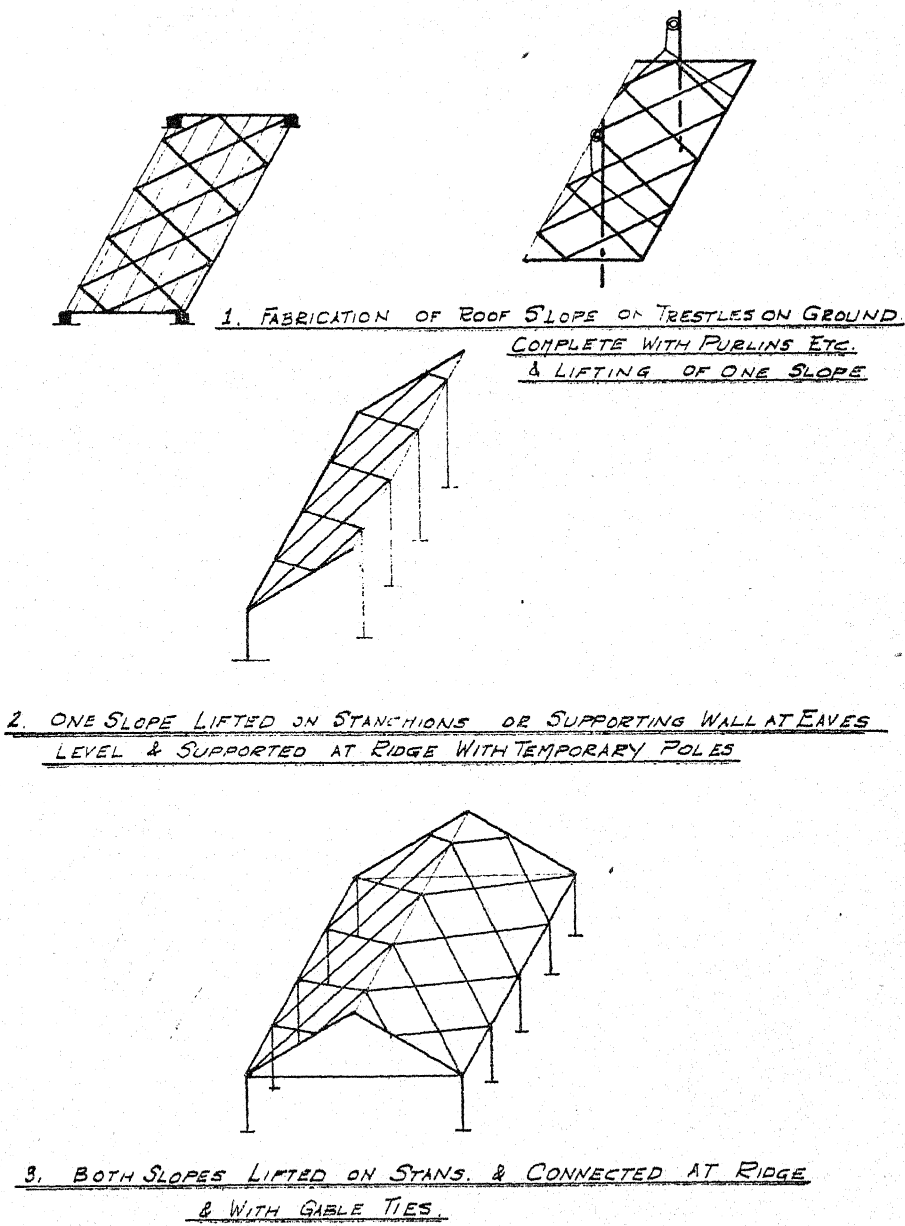


Fig. 31. Diagrammatic sketch showing ground-fabrication and erection of roof slopes of spatial grid, or roof.

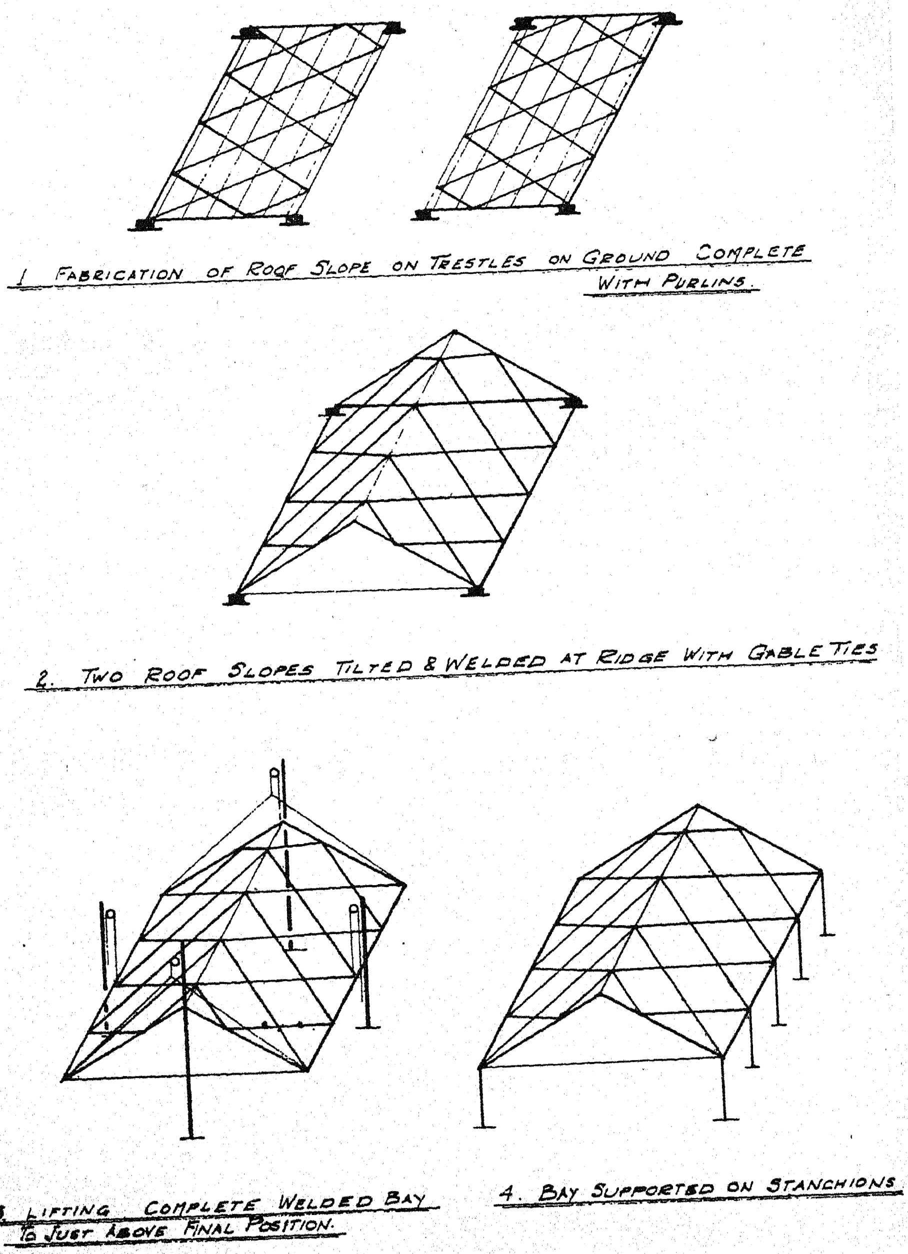


Fig. 32. Diagrammatic sketch showing four steps in assembly and erection of roof slopes.

lifting and propping the individual slopes which are large flat areas of steelwork. Those who have erected a large but light lattice girder for the umbrella type of roof will appreciate the objections to lifting in the horizontal plane what is, in effect, a deep lattice girder. It should be mentioned in passing that this method of erection is most useful for the single pitched roof or for the north-light type of roof, particularly in the former case where the roof is often carried on a concrete or brick wall at eaves level. In the latter case the north-light grid members may be erected piecesmall.

The next step, (See Fig. 32), took advantage of the inherent stiffness of two such diagonal roof planes when welded together at the ridge and tied to prevent spreading at the gables. Each plane is again assembled complete and welded at ground level on trestles. They are then tilted with the eaves or valley nodes still supported on the trestles. The ridge connection is made after the slopes are brought together and the planes are in their correct relative positions. They are bolted with temporary bolts at the ridge nodes, welded, and the gable ties and bracing are also welded in position. The ridge boom is lifted in position and welded, and this part of the structure is ready for lifting.

The arrangement of poles for lifting varies with the length and span of each such fabricated bay. One lifting pole at the ends of the ridge and others at intermediate valley or eaves nodes is a suitable arrangement.

The winches may be arranged in pairs so that the horizontal load in the lifting wires is opposed and thus balanced. The stanchions are then erected, plumbed and the bay lowered to them. It is necessary to support the valley nodes with temporary props until the next bay is erected and the welding between the two bays is completed.

Where there are a series of bays side by side, it is economical to arrange the lifting winches at one end of the structure so that they need not be moved until the whole series is erected.

A further development still—in the case of smaller structures of the multiple bay type—has been to assemble the whole structure at ground level and to lift it in one piece. The great stiffness of the diagonal grid structure enables this operation to be carried out quite rapidly and safely. A structure of three bays, 60′—0″ x 71′—0″ was lifted a height of 15 feet in one half hour.

Typical Examples of Monolithic Grid Structures

Factory at Bristol.—The structure consists of a row of square floor panels, (8 panels 22′—6″ square and 10 panels 20′—0″ square), supported on two rows of 8″ x 8″ precast concrete columns spaced at 22′—6″ and 20′—0″ centres. The grids were considered continuous in one direction and were designed for a superimposed load of 100 lbs. per square foot. The flooring material consists of a 2″ two-way reinforced concrete slab haunched down to the lower flanges of the 4¾″ x 1¾″ x 6.5 lb. R.S.J. grid beams ($S=2.83$ in^3) and the corner regions were filled with concrete to the full depth of the grid beams. The edge and intermediate members consist of 8″ x 3″ x 15.96 R.S. channels ($S=11.68$ in^3).

The grid beams were designed for a moment = 6,100 lb. ft. and were considered as composite sections with the concrete slab. The span to depth of beam ratio is 57 and the weight of steel in grid beams amounts to only 2.45 lbs. per square foot of plan area. A view of the grid beam and edge beam connections is shown in Fig. 33.

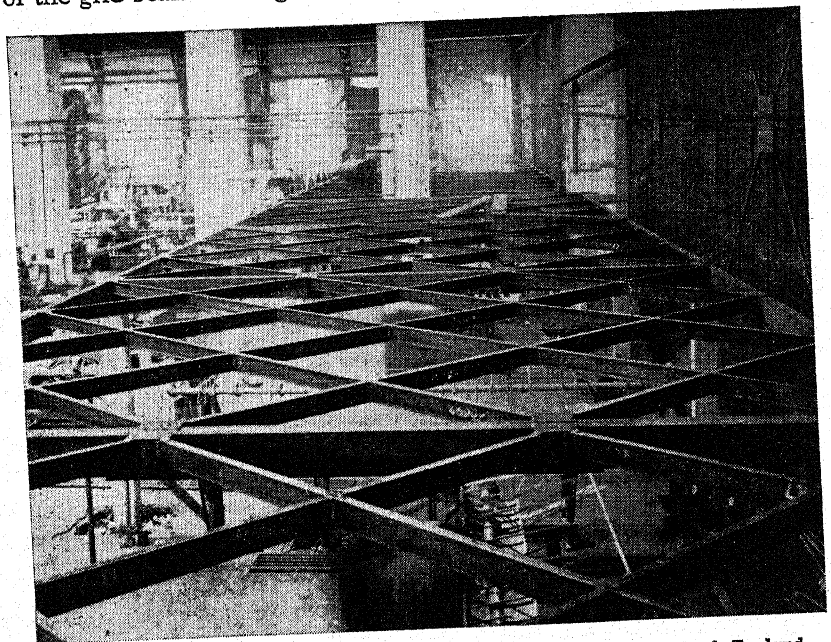


Fig. 33. Photo of grid beam-to-edge-beam connections in factory at Bristol, England.

Open Air School, Manchester.—The structure consists altogether of eleven roof panels of varying sizes, the largest individual panel being 26′—8″ square and the smallest 26′—8″ x 20′—0″. All are supported on steel stanchions at the panel corners. Some of the grids were cantilevered out to form a canopy and others were made continuous in one direction. The roofing material used is pressed steel sheeting with asphalt covering laid on a slope of 5°.

The grid beams are 4¾″ x 1¾″ x 6.5 lb. R.S.J. (S=2.83 in^3) and the design moment is 3900 lb. ft. The span to depth of beam ratio is thus 67, and the weight of steel in grid beams amounts only to 2.77 lbs/s. ft. of plan area. The edge beams are 6″ x 3″ x 12-lb. (S=7.00 in^3), 7″ x 4″ x 16-lb. (S=11.29 in^3) and 8″ x 4″ x 18-lb. (S=13.91 in^3) R.S. joists depending on the span.

The use of this very light form of construction is especially suitable for open air schools, providing an openness and graceful slenderness so necessary from the architectural standpoint. Fig. 34 is a view of the construction.

Drill Hall, London.—The structure, shown in Fig. 1, is a single pitch roof 82′ x 52′ in plan resting on concrete edge beams at eaves level.

The roof covering is asbestos cement tiling resting on timber boarding and rafters which are supported by the steel grid and steel purlins.

The absence of internal tie rods and bracings, etc., is very important because the structure is to be used for purposes which necessitate a ceiling higher in the central portion than at eaves level.

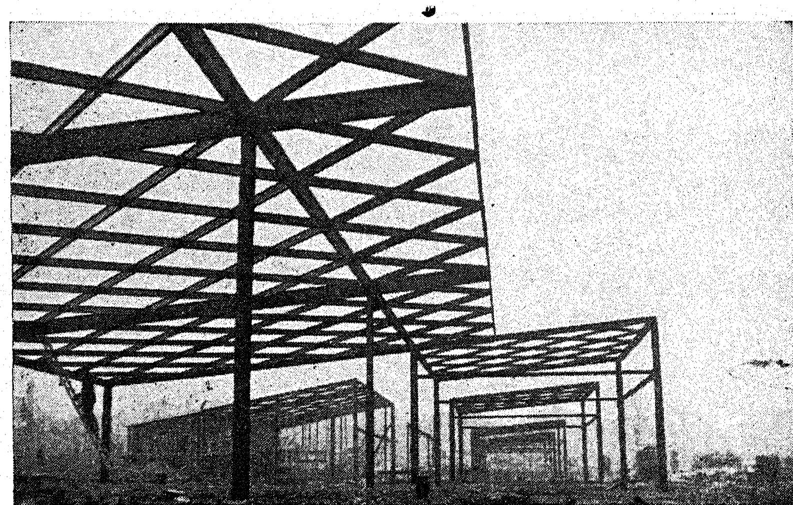


Fig. 34. Photo of grids in roof of open air school at Manchester, England.

The grid beams used are 7″ x 4″ x 16-lb. R.S.J. (S=11.29 in^3) plated where necessary for a design moment = 15,400 lb. ft. and direct force = 14,700 lbs. The span to depth of beam ratio is thus 89. The structure has a particularly pleasing appearance internally, as will be observed from Fig. 1. The gable ties are situated and encased in the gable walls.

Ice Rink, Blackpool.—The structure, (See Fig. 35), consists of a single pitch roof of 133′ span with one semi-circular end covered by a half cone. The longer dimension in plan is 150′ and there are no internal supports of any kind. Along the boundaries at eaves level the structure is supported on concrete columns and in the centre the apex of the half-cone provides a virtual support for one end of the pitched grid along the ridge. The roof covering consists of asbestos cement sheeting on timber boarding, and there are in addition a number of heavy concentrated loads suspended from the roof structure to carry lighting equipment. The roof slope in the grid portion is 22½°.

18″ x 6″ x 55-lb. R.S.J. grid beams (S=93.53 in^3) were designed for a moment = 157,500 lb. ft. and a direct force = 63,000 lbs. Edge beams are 16″ x 6″ x 50-lb R.S.J. (S=77.26 in^3). The span to depth of beam ratio is thus 100. Very efficient lighting is provided by patent glazing in the roof along the ridge which can be covered by blinds when required.

Badminton Hall, Epsom.—The structure, shown in Fig. 2, consists in plan of a single rectangular panel 78′ x 56′. In end elevation it is a parabolic arched grid roof with a rise at the centre of 12′. The grid is in six planes, the fold lines being parallel to the 78′ side. The roof covering is asbestos cement sheeting with patent glazing along the ridge.

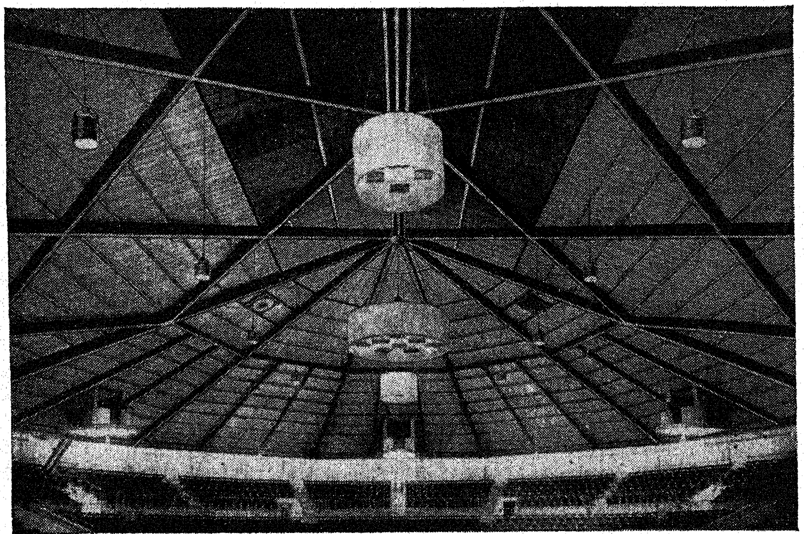


Fig. 35. Photo of interior of ice rink at Blackpool, England, showing all-welded grid roof.

There are no internal members below the roof planes, which is a special advantage in a structure of this type as the player's attention is not distracted. The grid beams used are 8″ x 4″ x 18-lb. R.S.J. ($S=13.91$ in^3) plated where required for a design moment = 16,500 lb. ft. and direct force = 23,900 lbs. The span to depth of beam ratio is thus 84. The arched shape considerably enhances the aesthetic appearance of the structure from within, over that of a normal roof. This is evident in Fig. 2.

Factory, Bristol.—The structure, shown in Fig. 3, consists of two independent panels 115′ x 90′ in plan, and is of a multiple ridge and valley type forming two gables along the 90′ side, the ridges and the centre valley being parallel to the 115′ side. There is a complete absence of internal supports, bracings, etc., steel stanchions being placed along the boundaries. The roof covering consists of corrugated asbestos cement sheeting and ceiling board, the slope of the roof planes being 22½° to the horizontal.

Apart from the roof loads, the grid is called upon to support a 10′ wide lavatory block along the centre valley, weighing nearly 1 ton per foot run. This was found necessary as these conveniences for the workers could not be provided anywhere else on the site.

10″ x 4½″ x 25-lb. R.S.J. grid beams ($S=24.47$ in^3) were thus called upon to take direct forces due to the heavy valley loads in addition

to bending from roof loads. The design moment was = 16,700 lb. ft. and the direct force = 104,000 lbs. The span to depth of beam ratio is 108.

Experimental Research on Welded Diagonal Grids.—A comprehensive program of experimental research work on diagonal welded steel grids was carried out between November 1935 and April 1936. All the tests were made under official supervision in Great Britain, with the primary object of obtaining a check on the analytical methods used for obtaining stresses and deflections, which have been already outlined in detail. A brief description of three series of tests, together with important results, are given here:

(1) Tests on three models of welded steel grids 4′-3″ square.

The tests were carried out at the City and Guilds Engineering College of the Imperial College of Science and Technology, under the supervision of Prof. A. J. S. Pippard. In all the three models the grid beams were 1¼″ x ¼″ flats, excepting the corner beams which were made from 2″ x ¼″ flats. The edge beams were 2″ x ½″ flats in all three models. The first model grid was open, the second one covered on one side by a continuous ¼″ top plate, and the third one had this ¼″ plate placed at the bottom in the corners instead of at the top. The floor plates were tack welded to the grid beams, so that they formed "T" sections.

The loading was applied by means of canvas bags filled with lead shot, which were borrowed from the Royal Aircraft Establishment, Farnborough. Deflection readings were taken at a number of different points with Ames' dials.

At a load of 240 lbs/s. ft. the deflections at the centre of the grid, apart from that of the edge beams were:

Model No. 1	0.289″
Model No. 2	0.058″
Model No. 3	0.030″

These figures indicate that model No. 2 with the continuous top plate is five times as stiff as model No. 1, and that model No. 3 is ten times as stiff as model No. 1. The ratio of stiffness for models 2 and 3 is as 1:2.

Among other things, the tests demonstrate the theoretical reasoning that the presence of bottom corner slabs increases the torsional rigidity of the corner beams and reduces the deflections and moments in the centre of the panel. This "corner action" has already been referred to.

A total of 12 tons load (1,490 lbs/s. ft.) was applied on models 2 and 3 without exceeding the limit of proportionality, as practically complete recovery was observed on unloading. However, on the assumptions that the straight line relation between load and deflection terminated at 10 tons load (1240 lbs./s. ft.) and that under this load a maximum stress of 33,000 lbs./s. in. was developed, the maximum positive moment carried at the centre of the bay would be = 33,000 x 0.139 = 4,580 in. lbs. The value 0.139 here represents the minimum section modulus of the grid beams considered as a "T" section with a flange width of 2″.

The calculated deflection and positive moment values were, in every case, greater than those obtained in the tests, thus demonstrating the conservative character of method of grid stress analysis and the additional margin of safety provided by welded diagonal grids.

(2) Tests on a full size floor bay 20′-0″ square with 6′-8″ cantilevers on all sides and supported on 4 columns at 20′-0″ centres.

The tests were carried out under the supervision of the Building Research Station of the Department of Scientific and Industrial Research.

The object of cantilevering the floor grid was to obtain the effect of continuity in all directions. The grid beams were 5″ x 3″ x 11-lb. R.S.J. ($S=5.47$ in^3) and the main beams between columns were 10″ x 4½″ x 25-lb. R.S.J. ($S=24.47$ in^3) designed for a total uniformly distributed load of 153 lbs/s. ft. or a superimposed load of 112 lbs/s. ft.

Fig. 36. Test of welded steel grid. Total load of 940 pounds per sq. ft. applied without causing failure.

Under the design load, the maximum grid deflection was just under 1 inch, that is, 1/240 of the span. The grid was then covered by a 2″ concrete slab reinforced cross-wise and haunched down to the bottom flanges of the grid beams. 2″ bottom slabs were provided in the corner regions adjoining the columns. Within a week of concreting, the loading was resumed and an actual grid deflection of 0.162 in. was recorded at the centre of the panel under the design load of 112 lbs/s. ft. This works out at 1/1480 of the span.

No stress measurements were taken during testing, but the deflection readings obtained for open and concreted grids were substantially lower than those derived analytically. Among other things, the test indicated the suitability and strength of this type of construction for floor structures where stiffness and minimum depth of construction are required. A total load of 220 tons was applied on the structure (equivalent to 940 lbs. per sq. ft.) without causing failure (See Fig. 36).

(3) Tests on a 37′ x 30′ folded grid roof structure.

These tests were also carried out under the supervision of the Building Research Station of the Department of Scientific and Industrial Research.

In plan, the structure consisted of 3 x 4 division grid, the 30′ side being divided into three equal parts and the 37′ side into four equal

parts. The grid was folded into four planes with a central ridge and two internal valleys each 30′ long. The grid beams were 7″ x 4″ x 16-lb. R.S.J. (S=11.29 in^3) and the edge beams along the 37′ side were 7″ x 3″ x 14.22-lb. R.S.C. (S=9.36 in^3) and 13″ x 5″ x 35-lb. R.S.J. (S=43.62 in^3) along the 30′ side which had no intermediate support. 7″ x 4″ x 16-lb. R.S.J. stanchions were used under each edge node along the 37′ sides. The roof planes were inclined to the horizontal at an angle of 22°.

The design load was 95.5 lbs/s. ft. and the structure was loaded to 363 lbs/s. ft. without reaching the yield point of the material. The test had to be discontinued at this stage due to the settlement of the supports. The maximum deflection of the grid proper under the design load was = 0.91 in, i.e., about 1/400 of the shorter span.

Deflection curves for individual grid beams were in fair agreement with those obtained by computation, and had much smaller ordinates at points of cranks than between two cranks.

(4) Tests on a Grid Beam Plane Intersection.

The following is a description of a test which was performed on a 7″ x 3½″ x 15-lb. R.S.J. Fig. 37 shows the beam before test, and it will be noted that the webs of the interrupted halves of the test beam were notched in line with the flange butt weld preparation.

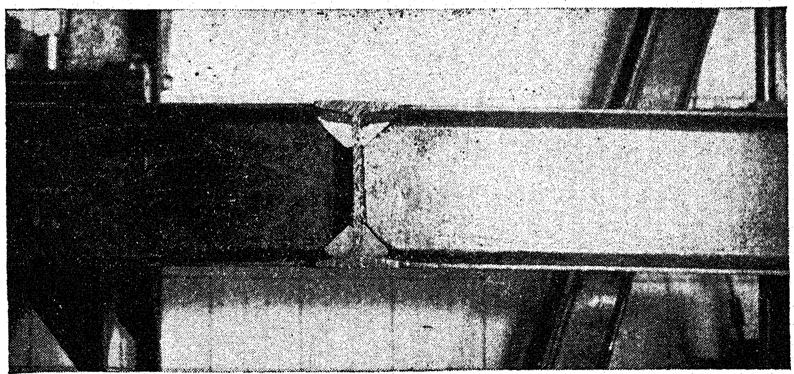


Fig. 37. Test of welded steel grid. Beam notched at web in line with flange butt weld—before test.

The test beam was supported on rollers at 3′—9″ c/c and loaded with a point load on the top flange of the short transverse beam. It should be appreciated that this condition of loading is far more severe than that which the connection undergoes in practice.

With a flange fibre stress of 8 tons/sq. in. the working load of the beam on the test span would be 7.3 tons. The departure from straight line or purely elastic deflection occurred at 12 tons load, when the maximum calculated fibre stress was 13.15 tons.

Failure occurred through buckling of the compression flange and ultimately of the tension butt weld at a maximum load of 23.5 tons. (See Fig. 38).

It will be appreciated that the butt welds do not develop the full

strength of the flanges spliced, as at the toe of the short transverse beam the flange thickness is considerably less than the mean flange thickness of the beams. To eliminate this weakness, the spliced flanges are now notched to the shape of the transverse flange, as shown in Fig. 20. The weld between the web of the spliced flange and the flange of the transverse beam increases the strength of the connection to equal that of an unbroken beam.

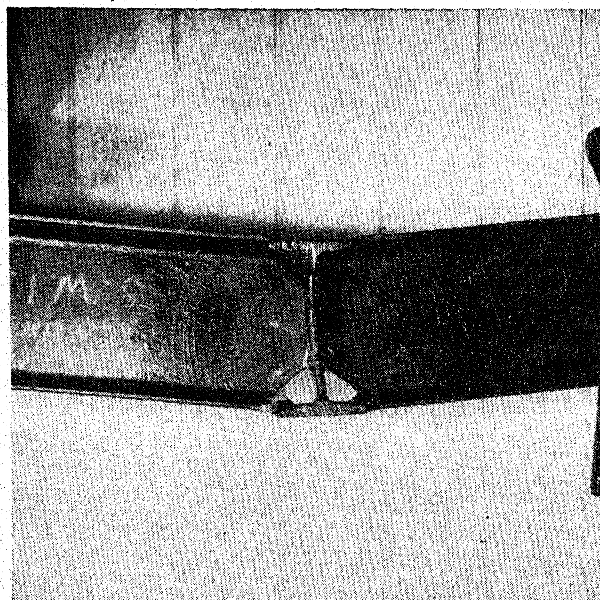


Fig. 38. View after test of beam. Failure occurred through buckling of compression flange at load of 23.5 tons.

(5) Tests on a model of Roof to Blackpool Ice Rink.

In order to investigate the distribution of stress in the roof of the structure erected at Blackpool, a model was prepared incorporating the main structural members, to scale of 1:33.3 in plan. The actual grid members in the model were 1″ x $5/16$″ flat with subsidiary tie members $3/8$″ x $1/8$″ flat, and the connecting welds were designed to develop the full strength of the members.

It was not possible to test the model in the testing machine available, because of its cumbersome shape, so it was decided to load it with a dead load. The point of application was to be at the main ridge detail and also at points in the centre of the grid beams in the slopes.

The load was transmitted to all points of support as in the structure itself, packing plates of varying thickness being placed at the eaves nodes to give equal bearing. The load applied at the apex of the semi-cone is illustrated in Fig. 39. Each of the pieces of steel forming the load was carefully weighed before being lifted into position.

Deflection readings were taken under the point of application of load with an Ames' dial, and strain readings in grid members also were taken

with the Huggenberger strainmeter. With a load of 8058 lbs. applied continuously over a weekend, the deflection at the apex remained constant at 0.0735 ins. This represents only 1/650 of the span of the model.

The stress figures obtained from strain readings showed remarkable conformity with those calculated.

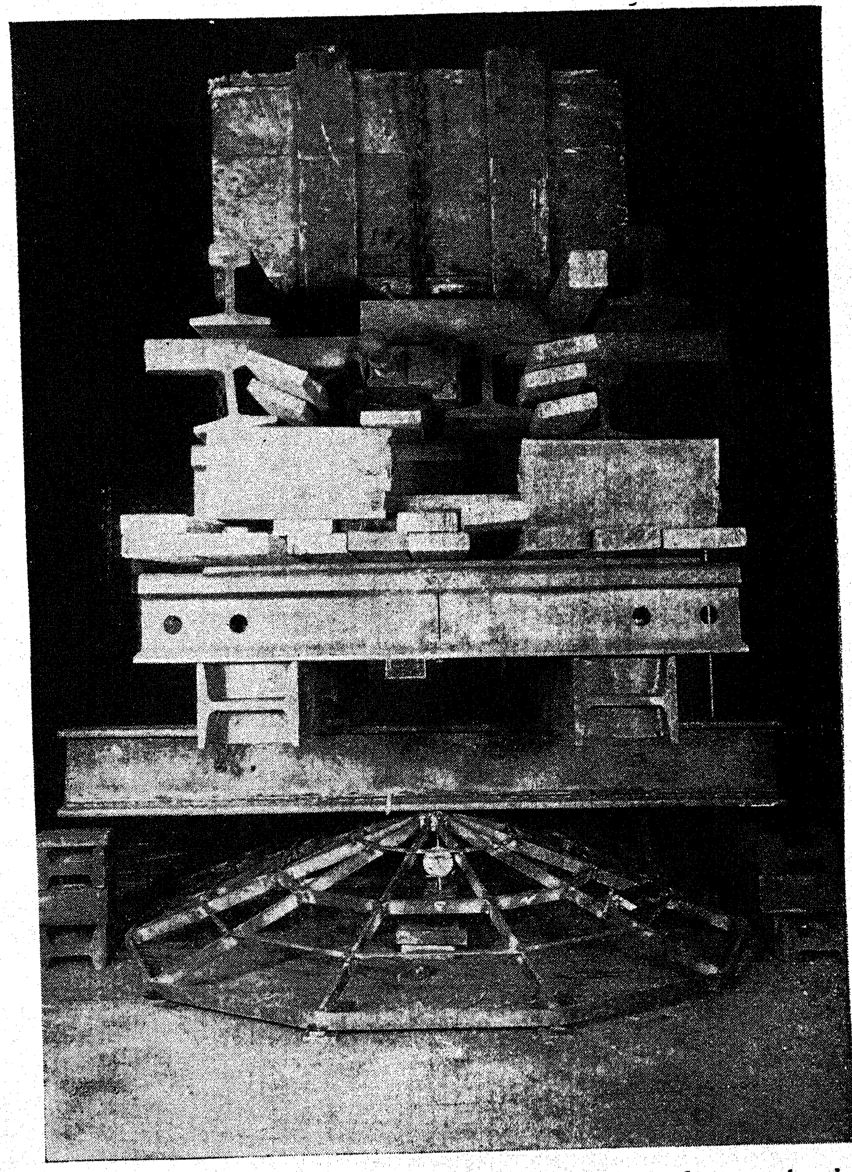


Fig. 39. Load of 8,058 pounds applied continuously over a weekend at apex of semi-cone of roof model caused deflection to remain constant at 0.0735 inches—1/650 of the span of the model.

Proportionate Cost Saving in Percentage of the Design Described in the Paper over Previous Design and Previous Method of Construction.—This aspect of the subject has been briefly dealt with but no attempt was made to go into details for the sake of brevity and lucidity. It is, however, now proposed to deal with the question of proportionate cost rather more fully than has hitherto been done. For this purpose, a factory at Birmingham will be selected, as it is considered to be a fairly representative type of industrial building, and is also one of the latest examples of welded diagonal grid structures.

The structure is 300′ x 175′ in plan, with columns spaced at 100′ and 35′ centres. Thus, in all, there are only eight internal stanchions. The design of this structure (which was satisfactorily completed some weeks ago*), is here compared with that of an orthodox north-light truss design with columns spaced at 30′ and 35′ centres, that is, 36 internal columns in all. The general outline of the orthodox riveted design was prepared so that a proper comparison could be made of the two schemes.

It will thus be noticed that the comparison is not quite equitable, as the design conditions for the orthodox scheme are much more favourable because of the very much smaller effective span, (30′ as against 100′ for the diagonal grid design). This, however, presents an excellent opportunity of demonstrating the inherent superior qualities of the welded grid design when compared with the conventional type as regards cost saving.

The following tables give particulars of steel weights in the two schemes:

Table I—Weight of Steel in Welded Grid Scheme

Section	Wt./ft. lbs.	Total Weight lbs.
Grid Beams 9″ x 4″ x 21 RSJ.	21	81,820
Grid Beams 9″ x 4″ x 21 RSJ.	21	14,450
Grid Beams 9″ x 4″ x 21 RSJ.	21	50,650
Gable Channels 8″ x 3½″	20.21	5,840
Gable Channels 8″ x 3½″	20.21	3,190
Gable Channels 8″ x 3″	15.96	9,220
Gable Channels 8″ x 3″	15.96	5,040
Edge Channels 8″ x 3½″	20.21	12,130
Purlins 4″x 1¾″ RSJ.	5	79,500
Ridge & Valley Angles 3″ x 3″ x ⅜″	7.17	19,360
Gable Ties 4″ x 2″ RSC.	7.09	4,610
Stanchions 8″ x 6″ RSJ.	35	16,070
Stanchions 9″ x 7″ RSJ.	50	7,500
Stanchions 6″ x 5″ RSJ.	25	1,450
		310,830
Connection plates 3%		9,300
TOTAL WEIGHT		320,130

$$\text{Steel per square yard} = \frac{320{,}130 \times 9}{300 \times 175} = 54.87 \text{ lbs.}$$

*At time paper was written.

Table II—Weight of Steel in Orthodox Riveted Scheme
(Factory at Birmingham—300′ x 175′)

Section	Wt./ft. lbs.	Total Weight lbs.
South Rafters 3½″ x 2½″ x 5/16″L	6.04	348.9
North Rafters 3½″ x 2½″ x 5/16″L	6.04	191.1
Tie 2—2½″ x 2″ x ¼″L	3.61	252.7
Bracings 3½″ x 3½″ x 5/16″L	7.11	56.8
Bracings 3″ x 2″ x 5/16″L	4.98	59.7
Bracings 3″ x 2″ x 5/16″L	4.98	47.3
Bracings 3″ x 2″ x 5/16″L	4.98	37.3
3″ x 3″ x 5/16″L	6.04	120.8
3½″ x 3½″ x 5/16″L	7.11	46.2
2½″ x 2½″ x ¼″ L	4.04	14.1
Wt. of steel in one truss		1174.9
Wt. of steel in 155 trusses		182,110
Longitudinal beams 18″ x 6″ RSJ.	55	99,000
Purlins 3½″ x 3″ x 5/16″L	6.58	108,570
Stanchions 10″ x 6″ RSJ.	40	39,800
Stanchions 6″ x 5″ RSJ.	25	13,000
		442,480
Gusset plates, rivets, etc. 16%		70,790
TOTAL WEIGHT		513,270

$$\text{Steel per square yard} = \frac{513{,}270 \times 9}{300 \times 175} = 87.98 \text{ lbs.}$$

It will be observed that the weights of steel in lbs/s. yd. for the welded grid and riveted truss designs are 54.87 and 87.98 respectively. This indicates a proportionate saving in steel =

$$\frac{87.98 - 54.87}{87.98} = 38\% \text{ approx.}$$

Assuming that riveted truss steelwork of this type can be carried out at the low rate of £24. per ton (2240 lbs.), the cost of the orthodox scheme in shillings per square yard of floor area is =

$$\frac{87.98 \times 24 \times 20}{2240} = 18.9.$$

The unit cost of steelwork for the welded grid design for the case under consideration was rather higher than the average and works out at £31.10. 0. per ton. In spite of this handicap, the cost in shillings per square yard for the welded grid is =

$$\frac{54.87 \times 31.5 \times 20}{2240} = 15.4.$$

Therefore, the proportionate cost saving in percentage is =

$$\frac{18.9 - 15.4}{18.9} = 18.6\%.$$

The Gross Savings Accruing to Industry through the General Adoption of the Design Described.—A reference to this matter was made in the opening paragraphs but it was considered to be a somewhat complex problem to prepare an estimate of world gross savings to industry through the adoption of the welded diagonal grid design which would at once be accurate and useful. This is principally due to the scanty classified statistical information available on the manufacture and application of steel for general structural purposes.

An attempt to assess these savings is, however, made here on the basis of information obtained from "Statistics of the Iron and Steel Industries" published in 1937 by the British Iron and Steel Federation of Great Britain.

The latest available figures on the production of structural sections in the principal countries of the world are given below:

	Country	Tonnage	Year
1	United Kingdom	1,726,400	1936
2	United States	2,897,000	1936
3	France	476,500	1936
4	Germany	5,528,300	1936
5	Belgium	382,800	1935
6	Luxemburg	401,300	1936
7	Japan	481,900	1935
8	Poland	269,600	1935
9	Russia	122,000	1933
10	Sweden	44,000	1936
11	Canada	34,600	1935
12	India	132,800	1936
		12,497,200	

It will be seen that approximately 12,500,000 tons of finished steel sections (joists, channels, angles, tees, etc.) suitable for structural purposes are produced annually. Of this total, however, only a part would be used for buildings, the rest being used for ships, railway coaches, bridges, etc. In the absence of any definite information available on the exact percentage of the total used for buildings, it will be assumed that about 50% of this is utilised for this purpose, that is, 6,250,000 tons.

Then again, the question arises as to the number and size of structures where the diagonal grid could be used profitably. It has already been stated that the field of application of this type of design is very wide indeed, and an estimated tonnage of 3,000,000 would seem quite a conservative figure where the diagonal grid could be suitably and usefully employed instead of prevailing types of structural arrangements.

The gross value of this steelwork at a low unit price of £20 ($100) per ton would be £60,000,000 ($300,000,000). As already mentioned, it is reasonable to assume that the adoption of the all-welded grid design would lead to an average saving of 20% in cost. From this then the gross savings accruing to industry work out at £12,000,000 ($60,000,000).

In conclusion, it must be stated that these economic advantages of the diagonal grid design, as outlined, are in addition to the many others which have been fully dealt with.

Chapter II—Construction of an All-Welded Building

By J. G. TSAGARIS,
Welding engineer, Erie Steel Construction Co., Erie, Pa.

This paper describes and analyzes the construction of a 100% all-welded steel building.

The building is of industrial, mill-type construction; sawtooth roof, 2 bays in width and 12 bays in length. In the east bay for the full length of the building is a mezzanine battle deck floor 22 feet from the ground, and on the west bay is a crane runway on 45-foot centers. The overall dimensions are 92′ 0″ in width by 300′ 0″ in length by 45′ 0″ to the highest point on the roof. The weight of structural steel involved is 360.1 tons. The Erie Steel Construction Company, Erie, Pa. designed,

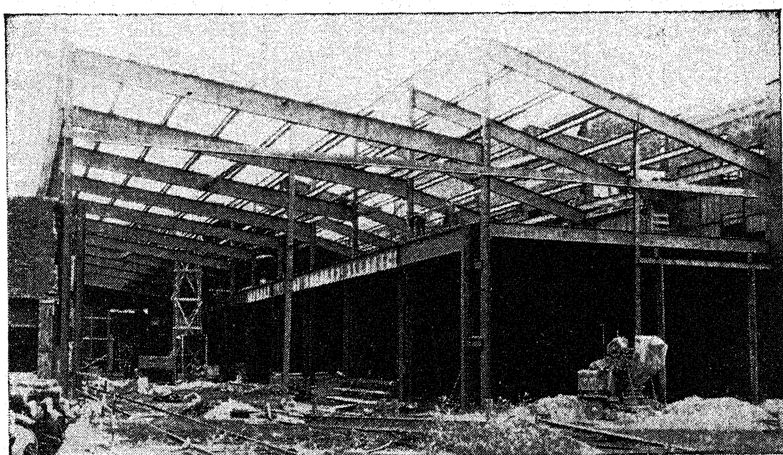


Fig. 1. The steel frame being arc welded.

fabricated, and erected the building. The erection work was begun June 18, 1937 and was completed five weeks later.

The scope of this paper will be an attempt to substantiate the claim that with the use of welded construction, this structure was built more economically, is superior in design and efficiency, has a much greater service life, and has contributed more for social betterment than would have been possible with riveted construction.

In reality, the building is an extension to an existing building, (See Fig. 1), where increased floor space was necessary. Halfway across the end of the existing building is an extension, or a wing, 300 feet long. The new building frames into the end and also along the full length of the wing. The west side of the new extension also frames into an existing one-story building. Thus, the new building abuts and frames into existing steel framework on one end and along two sides.

Welded construction was adopted because of its flexibility and also for the reason that it fulfilled the general requirements that the specifications covered, namely: maximum amount of light, simplicity in design, appearance and adequate clear floor area for machinery layout. Technical and economic consideration also were factors affecting the design. The peculiar and difficult field conditions where a large percentage of field connections were to be made to existing steelwork, weighed heavily in favor of welded design. The possibilities of welded construction were realized in deciding on battle deck construction for the mezzanine floor, which would have been decidedly impractical, as will be seen later in the discussion, if welding was not employed. With the administration and office building in close proximity to the building site, noise nuisance was given consideration. Time was a very important element since the building was to be used for an assembly line in manufacturing a mass-production product. Production schedules had to be met and it was recognized that welded construction would hasten the completion of the building. It was thought that the utilization of the crane girders which the owners salvaged from another building would be simplified by welding.

Many connections that had to be made to existing steelwork and many field connections to new steel were designed so there would be no pre-shop fabrication and also no field drilling. These were to be made by holding or clamping the parts in place until tack welded. It is obvious this would be possible only by welding. We were cautious, however, in going too far in the direction indicated. To facilitate erection, seats were adopted wherever practical. Enough erection bolts were to be used to hold the complete structure in place until welded.

Execution of Design and Details.—Referring to drawings, Figs. 2 and 3, a general plan and elevations of the structure are shown respectively. The columns shown in broken lines along the north and south sides in Fig. 2 are existing steel work into which the new structure is to frame. The columns 4C1, 4C2, and 4C3 are new steel and are designed to pick up, by means of angles 4A1, the roof beams of the existing one-story structure. Referring again to the existing columns on the north side, there are shown five lintels marked 12B1, made up of two 12″ channels @ 20.7 lbs. and plates 11″ x ¼″. These lintels, which are new, tie into the existing columns by means of two plates on each end, furnished loose and welded in place in the field. Tying into these columns also, in every bay, are 15″ channels as shown in Section PP, and again on the mezzanine floor line is another line of 15″ channels, framing as shown on Sec. PP.

On the south end are shown in Fig. 2 items 12B3 to 12B8 inclusive which are lintels, connecting to existing truss by means of clip angles. At section GG is shown the new end column field connection to bottom chord of present truss. At the extreme northwest corner the 30″ WF @ 108 lbs. rafter connects to the existing column. It may also be noted that the thirteen 30″ WF roof rafters, R1 and R2, also connect on the east side to the existing columns. On the mezzanine floor framework, the east ends of beams B1 connect to the existing columns. The end framing (shown on south elevation drawing, Fig. 2) such as door frames, struts

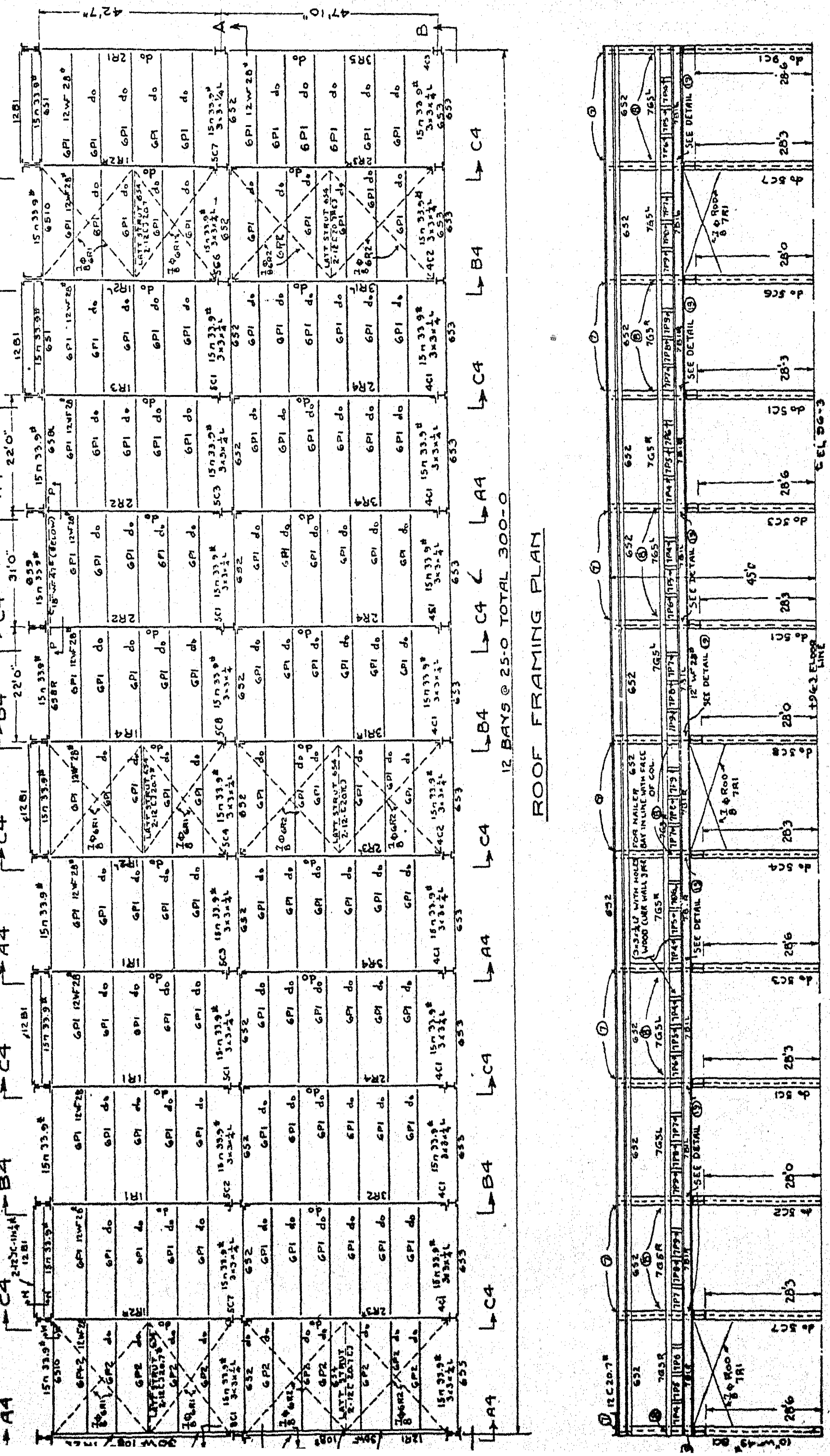


Fig. 2. General plan of the arc welded building. See also pages 464b and 464c.

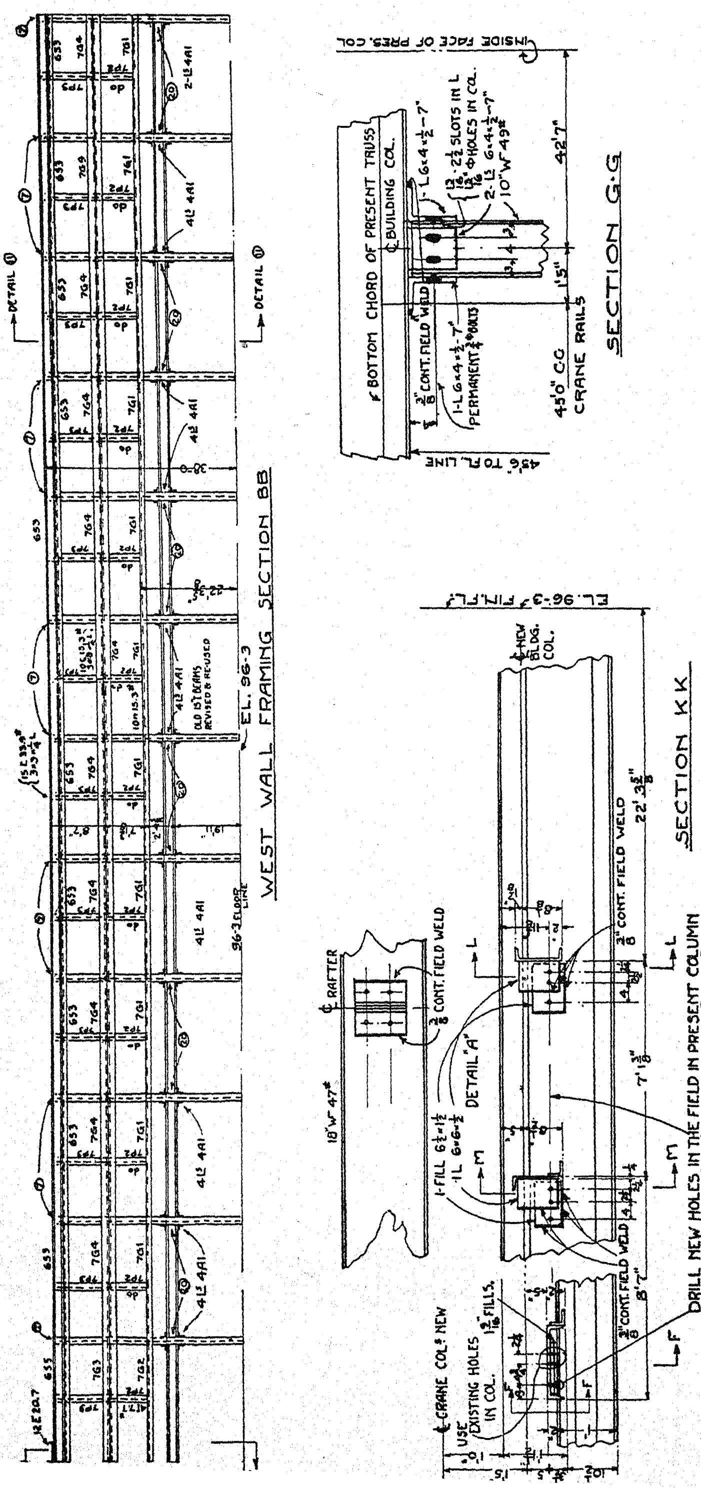


Fig. 2. Additional details of the arc welded building. See also pages 464a and 464c.

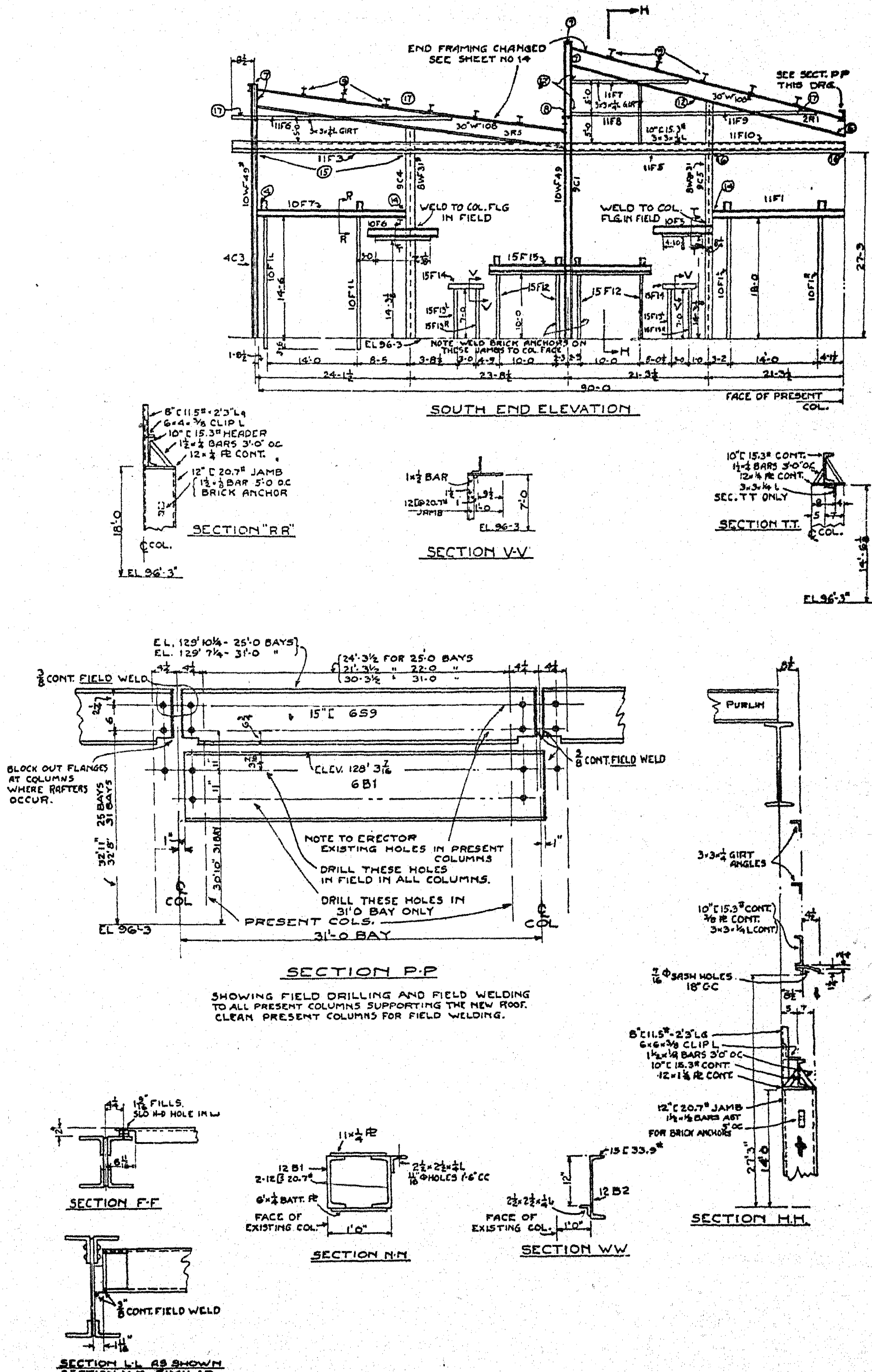


Fig. 2. Additional details of the arc welded building. See also pages 464a and 464b.

and lintels, were to be located and fitted in the field, eliminating a great deal of shop fabrication.

The supporting framework of the mezzanine floor is made of 21″ and 14″ wide-flange beams, with a row of 8″ columns in the center of the span. Transversely across the 14″ members are placed the 5″ floor beams on 30″ centers. These are tack welded to the supporting beams. The $3/16$″ floor plates are laid on top of the beams and tack welded. An angle iron railing encloses the mezzanine floor.

Turning now to the design of some of the typical connection details in Fig. 4, detail No. 1 shows a rafter-to-column connection. It consists of a 3″ x 3″ x $3/8$″ clip angle welded to the web of the 30″ WF rafter beam. The heel of the angle is continuously welded in the shop to the web. When the rafter is erected in position the weld at the heel forms a vee groove with the flange of the column. This groove is welded solid in the field. The function of the angle is to furnish a means for holding the rafter for field welding. The detail also shows welding on the vertical edges and around the top edges of both legs of the angle. The welds on the rafter web are specified so that the angle will not be damaged in handling, while the field welds are made to hook over the top edges of the angle so as to prevent initial tearing of weld.

This same type of connection was carried out on all supporting beam members meeting at 90° or at any other angle. A modification of this connection, Detail 6, Fig. 4, was used on some of the rafters-to-existing-column connections. This was necessary because some columns had no cover plate and the groove formed by the column web plate and angles was objectionable, since it appeared at the point where the field weld was to be made. Consequently a T-bar section was substituted for the clip angles. As in the case with the clip angle, the shop weld was made along the vertical and top horizontal edges of the outstanding legs of the T-bar. The simplicity of both these types of connections may be well appreciated if they are compared with their riveted equivalent.

Detail No. 9, Fig. 4, shows the treatment of purlin-to-rafter connections. A 3″ x $7/8$″ bar is shown welded to the rafter beam and a 6″ x 4″ x $3/8$″ angle welded to the bar. This device was resorted to in order to eliminate the handling and punching of the heavy 30″ WF rafter beams in the shop.

Detail No. 2, Fig. 4, is a detail of a typical column base. This is familiar design and in passing, it may be noted that provisions have been made to take care of uplift reactions due to crane loads.

Details No. 5 and No. 18, Fig. 4, illustrate typical crane girder-to-column and diaphragm connections. The girders are shown in place on the crane column caps and up against the diaphragms. They are shown continuously welded to the column caps and tack welded to diaphragms. It may be well to note that the girders were not new steel.

Shop Fabrication.—The solution of all the practical problems was left to the shop. In the first place, the work was intelligently planned, then scheduled to conform with the erection operations. Since time was an important element, just as quickly as members were completed in the shop, they were trucked to the building site where they could be

on hand ready for erection. In planning the shop work the following items were given consideration: the handling of materials, especially the heavy members, was kept to a minimum; the operations included in the preparation of materials such as layout, punching, flame cutting, milling and drilling were carefully supervised and checked so that there would be very little rehandling or going over.

In planning the procedure for the fit-up and welding operations, due consideration was given to the fact that extensive experience on big tonnage welding was lacking, therefore a flexible set-up of work was followed with the hope that knowledge of the correct procedure would develop as the work progressed. Truly enough, the work wasn't so very far along before the fitting-up, tacking and welding operations were performing successfully. The welding itself was all flat fillet work and very simple. However, careful attention was given to the contour of the welds on the ends of the 30″ WF rafter beams and on the ends of the mezzanine-supporting framework beams. It may be remembered that these welds form a vee groove which is welded in the field. It was therefore necessary that the welding be closely supervised and inspected in the shop. Strength welds were visually inspected while weld metal was being deposited and also after its completion. All welds were visually inspected after completion.

Field Erection.—Just as quickly as the steel erectors were through putting up the steel for the first six east side bays two welding gangs began their operations. Each connection to be welded was first checked for location, "taken up," inspected by the owners' and fabricator's inspector, welded and then inspected again. The crew that prepared the connections also shifted the welders' scaffolding. This procedure was followed throughout the job until every connection was welded.

An appreciable number of connections had to be made to existing steelwork. Many of these connections were not provided with erection bolts and were welded directly in place. The same was true of a number of secondary connections made on new steel. The flexibility of welded construction greatly simplified these connections.

The angle iron hand railing which was installed all around the edges of the mezzanine floor was fabricated in sections in the shop, each section fitting from column to column. Clamps were used to hold the sections in place while being welded to the floor plates and columns.

It was found that a great deal of the existing steel work was out of plumb and the old crane girders warped and not to dimensions specified. Had the connection to this steel work been pre-fabricated, as would have been necessary with riveted construction, serious difficulties would have been encountered in making these connections.

Comparison of Welded Construction with Riveted Equivalent.—In attempting to substantiate by comparison with riveted construction, the advantages obtained by using welded construction on this project, it must be said that in some instances it is going to be quite difficult to give definite conclusions as to the saving in cost resulting from its adoption.

However, it is believed that there will be presented enough definite proof supported with actual figures, that will substantiate conclusively

the advantages resulting from the use of welding. The main points that weigh in favor of welding will be taken up in order.

Savings in Weight.—Welded structures are considerably lighter than riveted because in the case of members subject to tension, no addition has to be made in cross section of a member to compensate for its reduction by rivet or bolt holes, and also because members meeting at an angle, usually 90°, can be either directly connected by a welded seam without the necessity of an angle cleat, or by cleats fewer in number and less in weight. On this job, however, the saving in weight will not appear to be especially pronounced, but nevertheless it cannot be neglected in the cost study. On the bulk of the structural members, whether riveted or welded construction were used, the design weight would have been the same with one exception, namely: the mezzanine floor supporting framework. The following table lists the members that made up the framework, their weights, and the sections required had riveted construction been used. Use of heavier sections with riveted construction would have been necessary owing to the loss in area due to the punching of holes that would be required.

STRUCTURAL MEMBERS AND WEIGHTS

	Welded Construction		Riveted Construction	
No. Req.	Member	Wt. Lbs.	Member	Wt. Lbs.
14	21″ WF @ 73 lbs.	39907	21″ WF @ 82 lbs.	44800
23	14″ WF @ 30 lbs.	16870	14″ WF @ 34 lbs.	19100
36	14″ WF @ 58 lbs.	51921	14″ WF @ 68 lbs.	60900
1	16″ WF @ 58 lbs.	1779	16″ WF @ 64 lbs.	1960
	Total weight............	110477	Total weight............	126760

It is noted that a saving of 15,283 lbs. of material was affected with welded construction on this item.

The next item effecting weight is in connection with the various connection angles required. To illustrate this point, let us for example look into the design of a typical 30″ WF rafter beam connection as shown in Fig. 4, Detail No. 9. Two 3″ x 3″ x 7/8″ clip angles are used, one on each end, whereas, in riveted construction four 6″ x 4″ x 3/8″ angles would have been necessary. This same condition occurs on all the beam connections throughout the job. There were approximately 175 various connection angles used having a total weight of 1750 lbs., whereas, in riveted construction there would have been 620 angles required, weighing 6995 lbs. Welding shows a saving in weight on this item of 5245 lbs.

On the column base and cap construction for columns, if riveted design were used, there would have been two additional clip angles required per column on the bases and two additional clip angles on the column caps, making a total of 212 angles weighing 2550 lbs.

The last but not the least important item showing a saving in weight for welding is the bracing. If Fig. 4 is referred to, it will be seen that three bays were braced with sag rods and built-up struts. Had riveted construction been used, at least two additional bays would have had to be

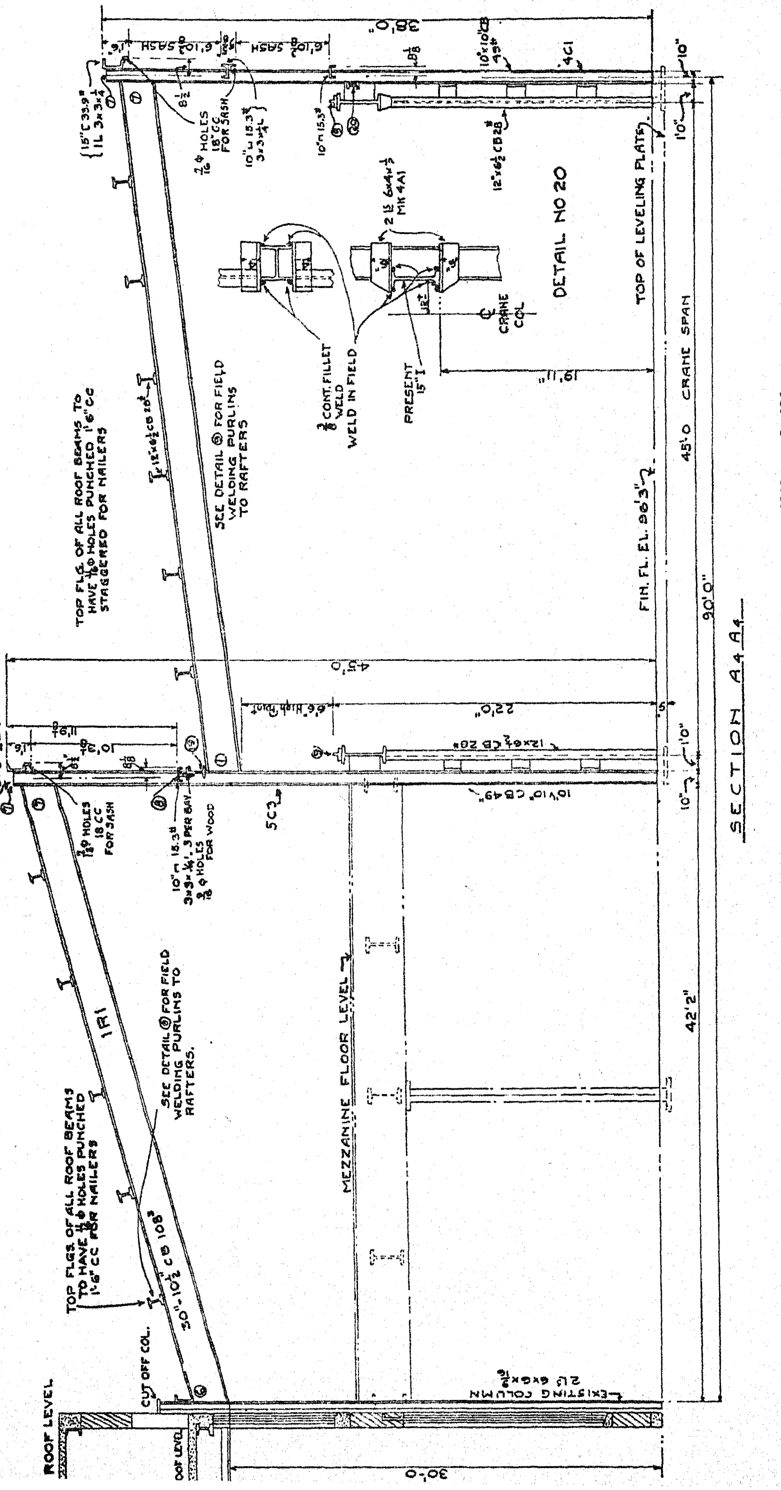


Fig. 3. Elevation at Section A_4A_4. See also elevations pages 466b and 466c.

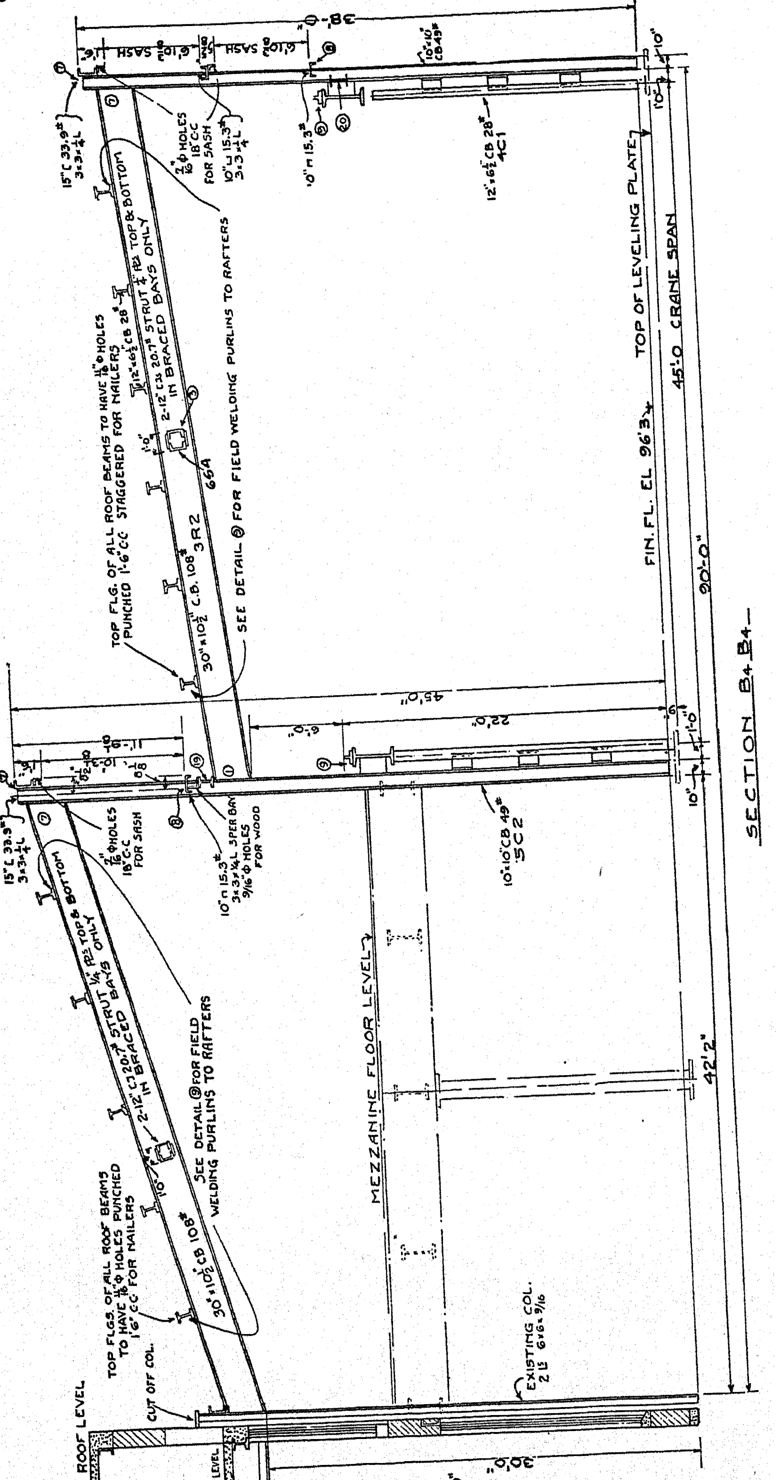


Fig. 3. Elevation at Section B_4B_4. See also elevations pages 466a and 466c.

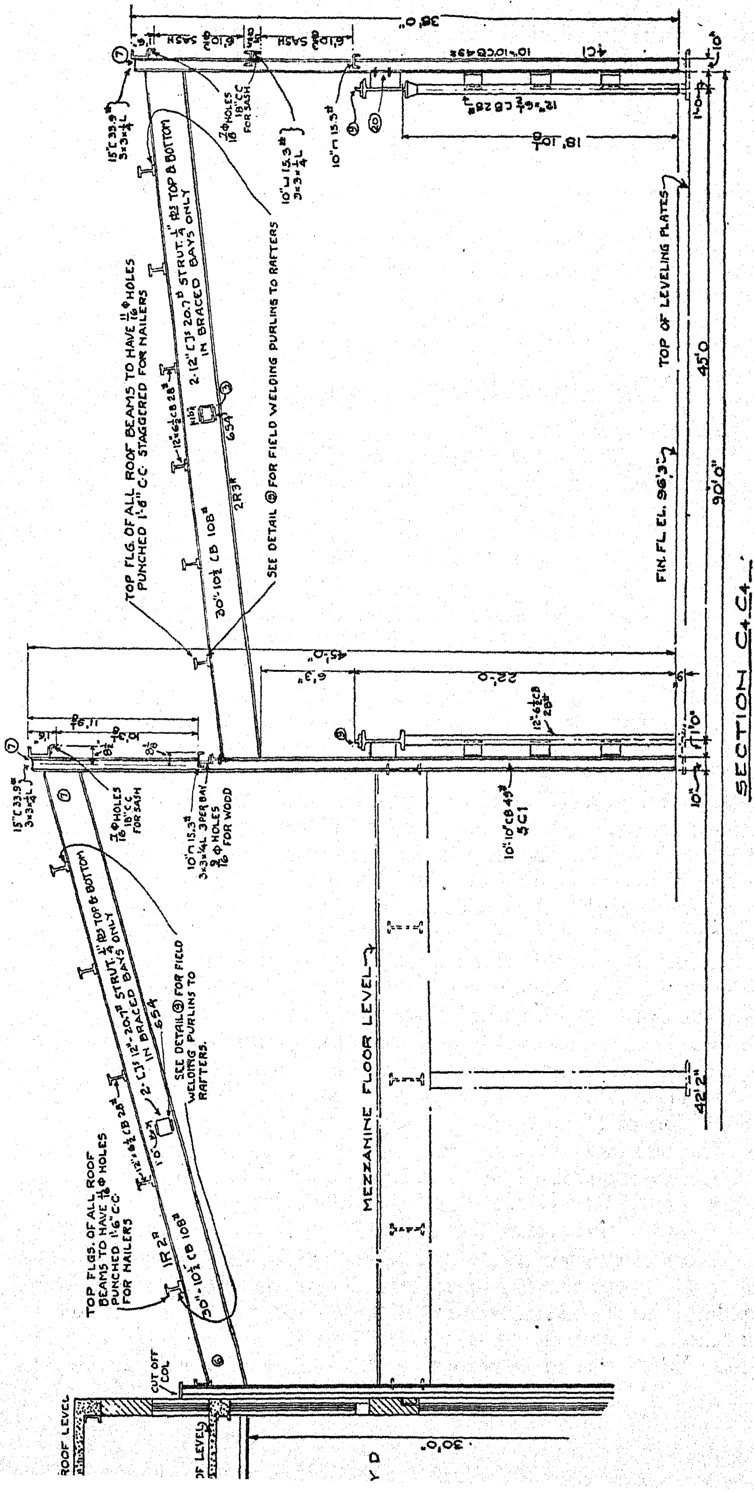


Fig. 3. Elevation at Section C_4C_4. See also elevations pages 466*a* and 466*b*.

braced in order to provide the equivalent rigidity that welding accomplished. On this item welding can be credited with approximately five tons of steel.

Thus we see from the above with the use of welding a saving of approximately 16¼ tons of steel, or 4.35%, has been accomplished.

Savings in Shop Costs.—The following items showed a saving for welding:

1. On the 30″ WF rafter beams there was no punching of holes. Outside of the taper cutting of the ends to size, there was no other preparation necessary. There were twenty-six of these rafters weighing 63 tons. The direct labor cost for handling, layout and punching, which was saved with welding, would have been $3.00 per ton of a total of $189.00.

2. On twenty-five 10″ WF crane columns and thirteen 8″ WF mezzanine floor columns no holes were necessary, therefore, the handling and punching operations were eliminated. These columns, including base plates, cap plates, and clip angles weighed 18 tons. At $4.50 per ton for direct labor, the saving was $81.00.

3. The direct labor cost in preparing the additional clip angles and connection angles that would have been required on riveted construction can be also credited to welding. These angles have a total weight of 7795 lbs. and the saving on this item amounts to $32.00.

4. On the mezzanine floor framework, the 14″ WF header beams were not required to be punched for connection angles or for the 5″ floor beams, as would have been required with riveted construction. There were thirty-six of these header beams weighing approximately 27 tons. The saving on handling and punching these beams was $135.00.

5. There were two hundred sixteen 5″ floor beams weighing 13½ tons, that were trucked directly to the building site, without any shop handling. Had the construction been other than welding, these beams would have required handling and punching in the shop. The saving in direct labor cost on this item was $45.00.

6. The mezzanine floor plates, of which there were two hundred forty pieces 60″ x 3⁄16″ x 10′ 0″ long and sixty pieces 60″ x 3′ 3″, weighing 50 tons, also were trucked directly to the site. If welding wasn't used it would have been necessary to handle the plates, layout, and countersink approximately 3360 holes. This would have cost $120.00.

7. On the miscellaneous lintels, roof struts, and framing, angle iron floor railing and other secondary structural members, having a total weight of approximately 40 tons, there was a saving in handling, layout and punching of $80.00.

8. The last item of saving in shop labor is in connection with the additional bracing that would have been required had riveted construction been used. To fabricate the 5 tons of steel for this bracing would have involved a direct labor cost of $60.00.

9. Of special importance and interest will be the comparative costs of the welding and riveting operations. There was a total of 310 hours of welding and the average hourly rate of welders, 80 cents. Thus the direct labor cost of welding was $248.00. The welding set-up cost was $175.00. With riveted construction, it would have been necessary to

drive 5500 rivets in the shop. Figuring the labor cost at $3.00 per hundred rivets, the total cost of riveting would have been $165.00. Set-up labor for riveting would have been $150.00.

Summarizing the above items in connection with shop labor costs, the results indicate a saving of $742 for welding and $208 for riveting, or a net saving for welding of $534. Adding to this figure, the cost of indirect shop labor, which is 25% of direct, the total labor cost saving that can be credited to welding will be $667.50 or 34%.

Field Welding Cost Study.—The peculiarity of some of the construction such as for example the mezzanine floor, and the extremely difficult conditions in the field, where so many field connections had to be made to existing steelwork, gave welding on this structure an exceptional advantage over riveting, as will be conclusively shown.

1. Out of a total of 1975 field connections of all kinds made in the field, not including floor plates, 250 were made to existing steelwork. It is also significant and worth noting that 1250 connections required no shop preparation of material. On the field connections to existing steel, had riveted construction been used it would have been necessary to drill in the field 2225 holes for rivets. Deducting the 210 holes that were necessary for field erection with welding, the direct labor cost saved by welding was $302.00.

2. There would also have been required, the field drilling and countersinking of thirty three hundred sixty $\frac{9}{16}''$ holes to the two hundred sixteen 5″ floor beams and thirteen 21″ WF supporting beams, for attaching floor plates, had not welding been used. It would not have been practical to make these holes in the shop and trust that they would line up and match the countersunk holes in plates. The saving welding accomplished on this item was $336.00. This can be considered a net saving since the welding of these plates, which required eighteen hundred $\frac{3}{16}'' \times 2''$ tack welds, would cancel the cost of fastening thirty-one hundred sixty $\frac{1}{2}''$ countersunk head bolts.

3. In the erection of the railing, which extended around the edges of the mezzanine floor, there were required two hundred fifty $\frac{1}{4}'' \times 2''$ tack welds to weld the railing to the floor plates and one hundred sixty-eight $\frac{1}{4}'' \times 2''$ tack welds to weld it to the columns. Had the railing been erected by riveting or bolting, it would have been necessary to drill two hundred fifty holes into the plates and ream 168 holes in the columns. This would have cost $35.00.

4. On the 24 crane girders, which were old steel furnished by the owners, welding eliminated the necessity of field drilling holes in these girders for riveting end to end and on to the crane columns. There would have been 864 holes necessary costing $96.00.

5. Welding can also be credited with the saving in labor on the erection of the additional bracing and struts in two bays that would have been required with riveted construction. These members would have weighed 5 tons. Estimating the labor cost at $11.00 per ton a saving of $55.00 for welding was realized.

6. The final and perhaps most important item of comparative costs is the field welding versus field riveting operations. The total direct field welding time was 405 hours and the welding labor rate $1.25 per

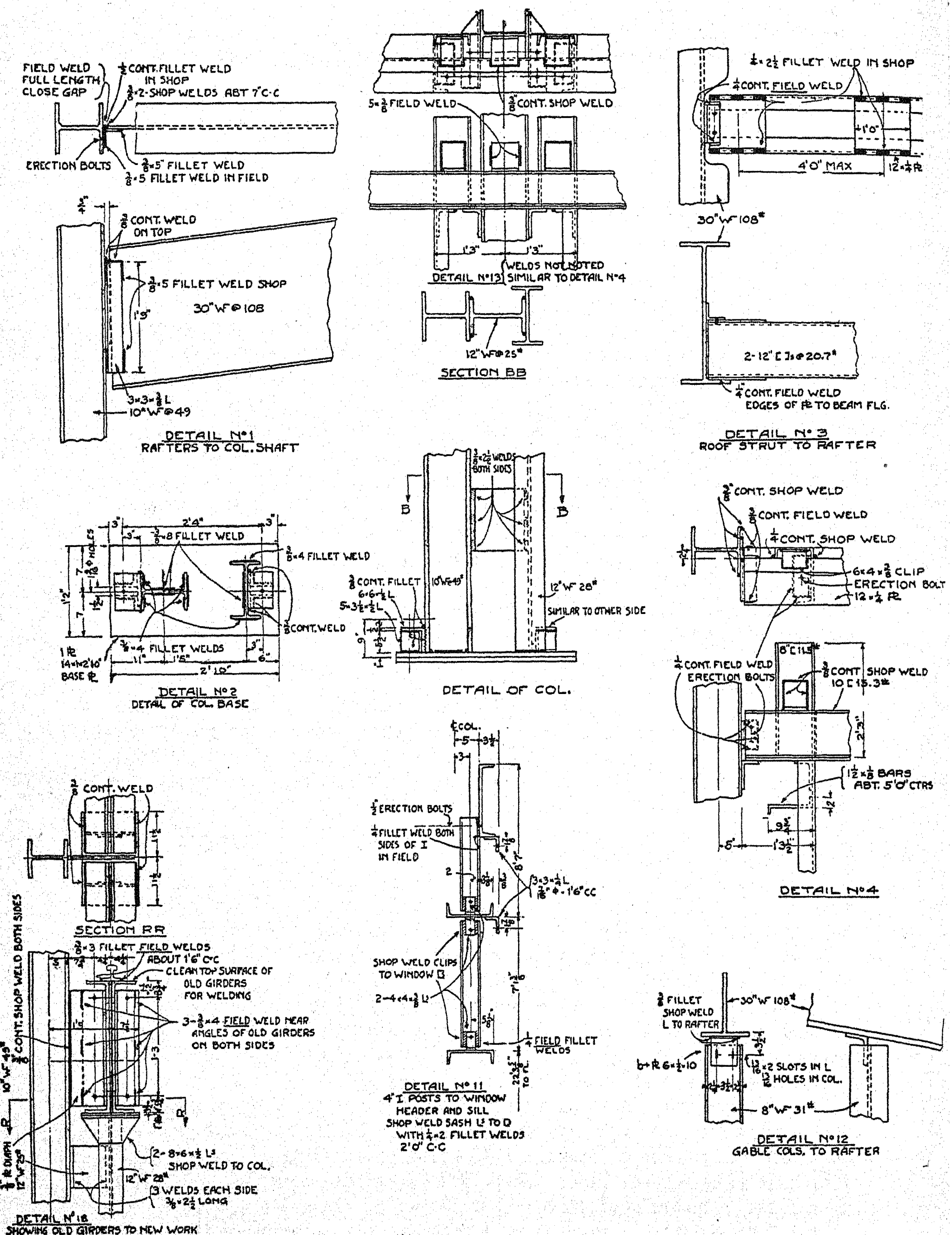
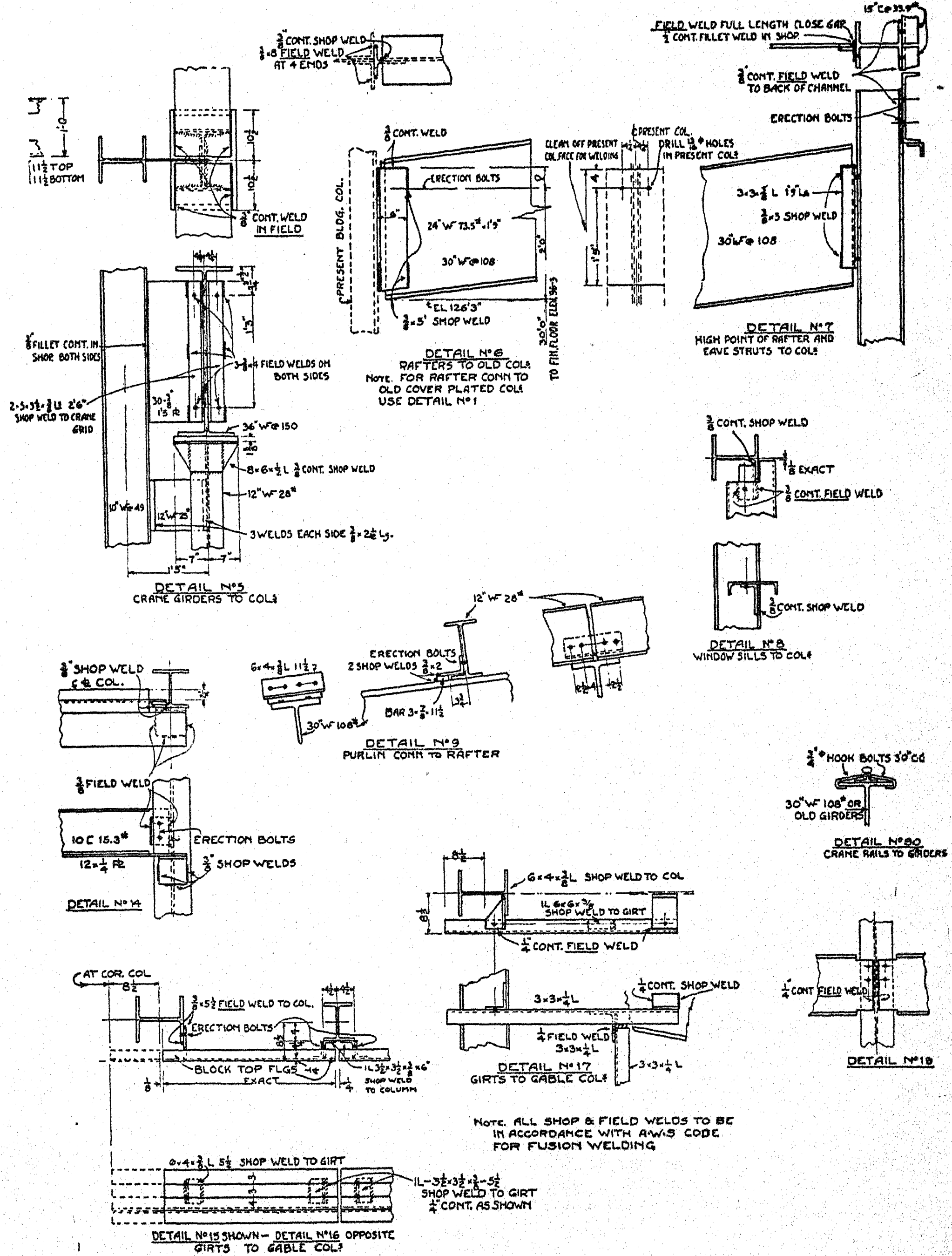


Fig. 4. Typical arc welded connection details.



DETAIL Nº5
CRANE GIRDERS TO COLS
36" WF@150
12" WF 28#
10" WF 49
3 WELDS EACH SIDE
DETAIL Nº6
RAFTERS TO OLD COLS
NOTE. FOR RAFTER CONN TO OLD COVER PLATED COLS USE DETAIL Nº1
PRESENT BLDG. COL.
ERECTION BOLTS
24" WF 73.5# × 1'5"
30" WF@108
EL 126'3"
TO FIN. FLOOR ELEV. 96'3
DETAIL Nº7
HIGH POINT OF RAFTER AND EAVE STRUTS TO COLS
FIELD WELD FULL LENGTH CLOSE GAP
CONT. FIELD WELD TO BACK OF CHANNEL
ERECTION BOLTS
30" WF@108
DETAIL Nº8
WINDOW SILLS TO COLS
CONT. SHOP WELD
CONT. FIELD WELD
DETAIL Nº9
PURLIN CONN TO RAFTER
ERECTION BOLTS
12" WF 28#
30" WF 108#
DETAIL Nº 14
SHOP WELD
FIELD WELD
10 [15.3#
ERECTION BOLTS
SHOP WELDS
DETAIL Nº80
CRANE RAILS TO GIRDERS
HOOK BOLTS 3'0" CC
30" WF 108# OR OLD GIRDERS
DETAIL Nº17
GIRTS TO GABLE COLS
SHOP WELD TO COL
CONT. FIELD WELD
CONT. SHOP WELD
FIELD WELD
DETAIL Nº18
CONT FIELD WELD
AT COR. COL
ERECTION BOLTS
BLOCK TOP FLGS
EXACT
SHOP WELD TO COLUMN
SHOP WELD TO GIRT
DETAIL Nº15 SHOWN— DETAIL Nº16 OPPOSITE
GIRTS TO GABLE COLS
NOTE. ALL SHOP & FIELD WELDS TO BE IN ACCORDANCE WITH A.W.S. CODE FOR FUSION WELDING

hour, making a labor cost of $506.00. Welding must also be charged for labor in connection with the moving and preparing of scaffolding, taking up joints and clamping or holding connections where no provisions for erection had been made. The cost of this added labor was $336.00. The total cost of welding and preparations is then $842.00. In examining the cost of riveting, there would have been 1200 rivets to drive into connections to existing steel work. Owing to their inaccessibility for riveting, these rivets would have a higher rate of cost than those on new steel. Estimating the cost at 35 cents each, we have a labor cost of $420.00. In addition, there would have been 3000 more rivets to drive. Estimating these at 20 cents each, we arrive at a cost of $600.00, making a total labor riveting cost of $1,020.00. Comparing this figure with the welding labor cost of $842.00 there is obviously a net saving of $178.00 for welding.

Summing up the items that have shown a saving for welding on field erection, the result indicates a total saving of $1,002.00 or 30.5% of the total labor cost in the field. The figures are itemized in the following table.

COST SAVINGS IN SHOP AND FIELD WITH WELDED CONSTRUCTION

Item No.	Description	Cost Saved Direct Labor Dollars	Cost Saved Direct Labor %
	DIRECT SHOP LABOR		
1	30" WF Rafter Beams	$189.00	
2	10" WF Crane Columns	81.00	
3	Connection Angles	32.00	
4	Mezzanine Floor Framework	135.00	
5	5" Floor Beams	45.00	
6	Mezzanine Floor Plates	120.00	
7	Lintels, Misc. Members	80.00	
8	Additional Bracing	60.00	
	Total	$742.00	
	Deducting Item No. 9	208.00	
		$534.00	
	Add 25% Indirect Labor	133.50	
	Total Net	$667.50	34
	DIRECT FIELD LABOR		
1	Drilling Field Connection Holes	$302.00	
2	Drill Countersunk Holes for Plates	336.00	
3	Railing Erection	35.00	
4	Crane Girders	96.00	
5	Erection Additional Bracing	55.00	
6	Welding	178.00	
	Total Net	$1,002.00	30.5

It will be well to emphasize here, that it has not been possible to determine the savings accomplished on many other items not specifically mentioned above. But there were many such and by witnessing the work, we cannot escape the conclusion that important savings in shop and field labor resulted from the flexibility of action made possible with welding.

The time element, which was the essence of the work from start to finish, was more easily controlled than would have been possible with riveted construction. Simply by adding one or two more welders the work was expedited as required. It became evident that had riveted construction been used, the completion of the steelwork would have been delayed by at least two weeks. How much this would have meant to the owners in actual dollars and cents, would be difficult to hazard a guess. Unquestionably, time was saved in the drawing room in making the details and shop drawings. In the shop there was less indirect labor involved than with riveted construction on operations such as stocking and sizing of incidental materials and supervision. Simplification of production, together with reduced weight resulted in general economies all along the line.

But, even more important than any of these intangible items of saving, is the indirect savings made on the design and construction of the mezzanine floor. It is extremely doubtful, that it would have even been attempted to incorporate this battledeck type of floor had not welding been the means of fabrication.

The cost study does not as yet throw any light upon the vitally interesting question as to what the owner or customer saved on his contract prices with welded construction. The following table has been prepared to show this. For the sake of simplifying the cost set-up, indirect expenses, such as overhead, liability, compensation, profit, etc., have been lumped, and the selling price figured on a direct ratio based on material and labor costs.

SAVINGS IN DOLLARS AND PERCENT ON SELLING PRICE WITH WELDED CONSTRUCTION

	Riveted Construction Direct Costs Dollars	Welded Construction Direct Costs Dollars	Ratio Selling Price to Direct Costs Dollars	Selling Price Riveted Dollars	Selling Price Welded Dollars	Savings on Welded Dollars	Saving %
Material	$17,150.00	$16,410.00	$\frac{1.15}{1}$	$19,723.00	$18,872.00	$ 851.00	4.32
Shop	1,964.00	1,297.00	$\frac{6.1}{1}$	11,980.00	7,912.00	4,068.00	34
Field	3,287.00	2,285.00	$\frac{2.2}{1}$	7,231.00	5,027.00	2,204.00	30.5
Total	22,401.00	19,992.00		38,934.00	31,811.00	7,123.00	18.3

NOTE:—Above table shows welded construction saved the owners $7,123.00 or 18.3% on the contract price.

Besides the technical and economic advantages, without a doubt, the structure is far superior in construction than its riveted equivalent. The rigidity of the welded connections gives it a greater life expectancy and therefore a higher service life efficiency. The smooth mezzanine floor surface made possible only with welding, provides operating advantages that are quite important to the type of service and the operating conditions to which it will be subjected.

Social Advantages.—The principal considerations in determining what contributions the building of this welded structure has made toward social betterment, are by nature economic, progressive, labor saving, aesthetic and civic. The first has been conclusively discussed in the foregoing cost study. The second—progressive—will also be substantiated if it will be admitted that the experience gained by the building of this structure has added to the store of human knowledge, and this should be significant to everyone who seeks to improve his use of a comparatively new method of joining metals. Undoubtedly, it has encouraged the spread of the new psychology of product improvement and development, which seems to pervade the whole industry at present. Riveted construction would not have added one iota to what is not already known about it, nor would it have inspired anyone to redesign his product. In connection with the third consideration—labor saving—anything that contributes to the improvement of labor conditions or to labor efficiency; such as lessening the drudgery, by simplifying production, reducing weights, and eliminating nerve-racking noise, surely has furthered to a degree social improvement.

The fourth consideration—aesthetic—although not so very important on an industrial building, it nevertheless, has been given attention, and the advantages of welding recognized. The simple, pleasing appearance due to the aesthetically excellent disposition of surfaces made possible only by welded connections, has an obvious advantage over riveted structures, which leave much to be desired in this respect.

The last consideration—civic—cannot be overlooked since it deals with the public. The elimination of noise during construction has been given a great deal of thought in recent years. Surely the superiority of welding over riveting is very apparent, infringing less on the rights of the community by eliminating a source of distressing, fatigue-causing nuisance.

Chapter III—A Welded Industrial Building

By Gilbert H. Atwood,
Assistant chief draftsman, Dravo Corp., Pittsburgh, Pa.

In the fall of 1936 the Dravo Corporation decided to increase its production facilities by the addition of a building suitable for erection and final assembly of barges, towboats, or other marine or structural units. Immediately, certain basic data had to be considered and settled before the detail design and preparation of shop drawings might proceed. Those problems having to do with size, location, type of crane service, lighting, heating, etc., have no relation to the question of welding and therefore will not be here discussed. Other questions, however, which had to be answered were directly concerned with welding. These were questions of cost, time of completion, and suitability from a structural standpoint.

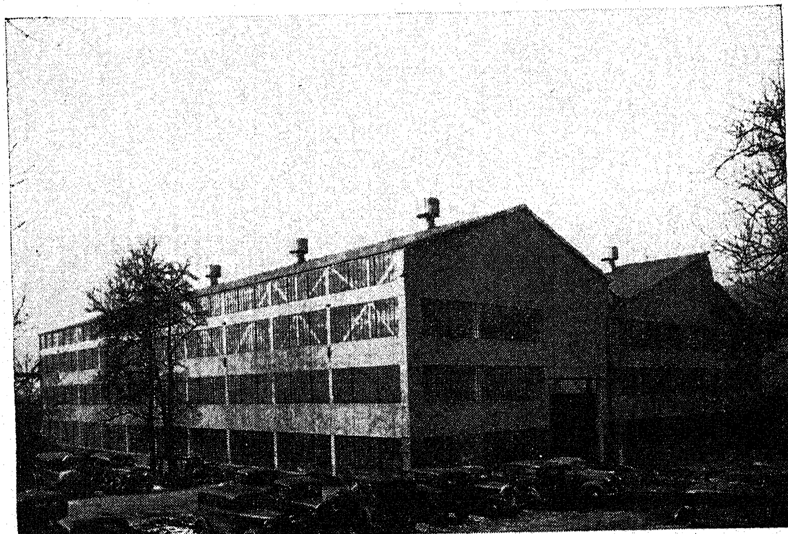


Fig. 1. Barge assembly plant of arc welded construction.

Discussion of those questions led finally to the following conclusions.

1. It would require a smaller expenditure to fabricate and erect a welded structure.
2. A welded structure could be completed and put in operation in a shorter period of time than if it were riveted.
3. The use of welding throughout the structure would be entirely feasible and suitable.

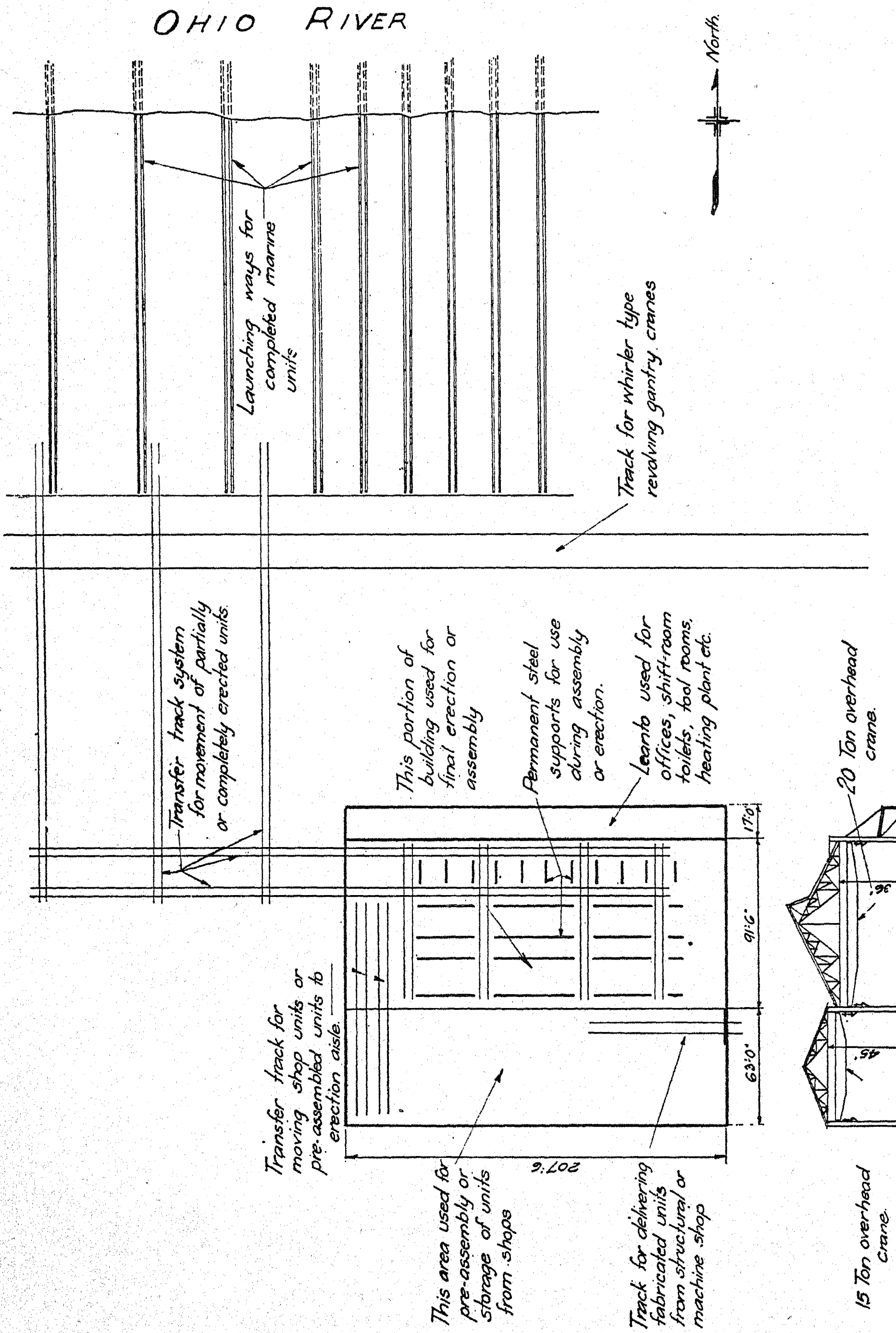


Fig. 2. Layout of building.

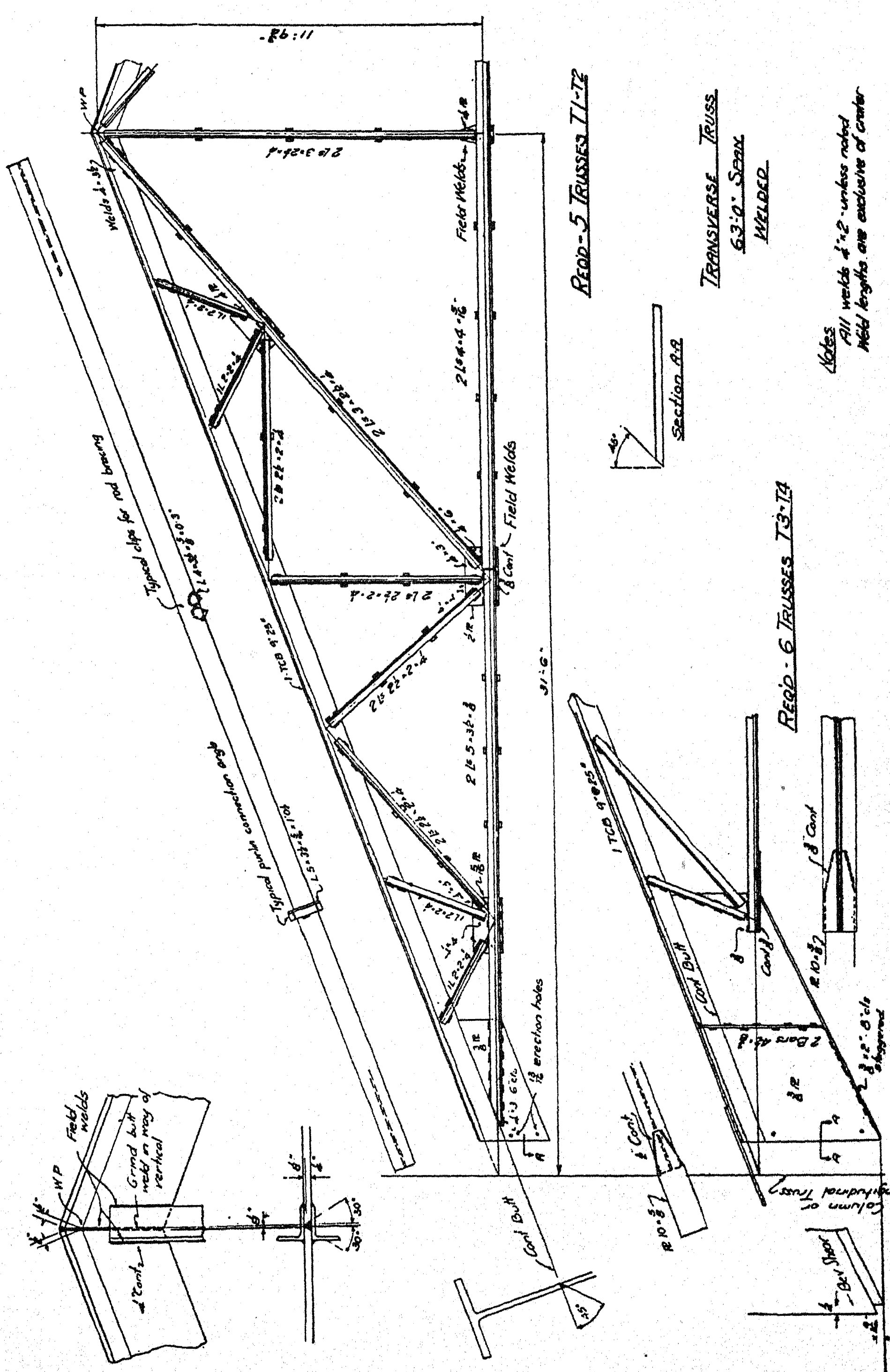


Fig. 3. Sketch of typical 63-foot span truss.

4. The welded structure would be more appropriate for an organization whose output consists very largely of welded units. To both the casual visitor and the prospective customer the welded building would serve as a permanent exhibit of the adaptability of welding and our own faith in its use.

Accordingly we immediately went ahead with the structure on the basis of a welded design and the work was brought to completion early in 1937. (See Fig. 1).

The structure proposed for this discussion is relatively small but carries fairly heavy crane loads and, in addition, has other unusual features.

Design and Description of Present Structure.—The layout of the present structure is as shown in Fig. 2. A brief study of this sketch will enable the reader to follow the text with a clearer understanding.

It will be noted that the structure consists essentially of two parts one of which is 63′-0″ wide and 207′-6″ long and the other of which is 91′-6″ wide and 207′-6″ long. These areas are entirely free and unobstructed, that is, there are no columns inside of the structure except the line of columns between the 63′-0″ aisle and the 91′-6″ aisle. The narrower aisle is used for storage of materials from the fabrication shops and for the making of pre-assemblies of various units before final erection and will hereafter be called the pre-assembly aisle or pre-assembly bay. The wider aisle is used for final erection and will hereafter be called the erection aisle or erection bay. The pre-assembly aisle is served with a 15-ton overhead crane spanning the entire aisle and is somewhat higher than the erection aisle. This additional height is required by the necessity of turning over large pre-assembled units in order to position any welding which may be done in this aisle. The erection aisle is at present served by a 20-ton overhead crane spanning this entire aisle.

Briefly, this building is designed to function as follows: fabricated material is delivered on railroad cars from the structural shop, machine shop, or pipe shop to the pre-assembly aisle where it is unloaded. This material may or may not be required to be made into sub-assemblies before the erection. Whether or not this is the case, the material is finally delivered to the erection aisle by means of the transfer tracks across the extreme west end of the structure. Final assembly is made in the erection aisle and the unit is then ready for delivery.

Due to the size of units which this shop was intended to handle it was necessary to make the entire west end of the structure of doors. The complete end of either the pre-assembly aisle or the erection aisle may be opened at any one time although both may not be completely open at the same time. This requirement makes it impossible to use the west end of the building as a wind frame for north or south wind components and consequently other provision had to be made for these wind loads.

In addition, the structure was designed so that an additional erection aisle might be later added to the south side of the present pre-assembly aisle. This made it inadvisable to fabricate and install wind bracing in the south face of the building also.

Considerations of floor space dictated that both aisles be kept entirely free of building columns and that very few columns be used in the line between the two aisles. Therefore, only four intermediate columns were used making the column spacing on this line 41′-6″. Inasmuch as economical design dictated transverse trusses every 20′-9″, these must of necessity frame into longitudinal trusses carried by the columns. On the south face, temporary light intermediate columns were provided between the main columns which are spaced the same as on the center line. These light columns are intended to be removed if and when the structure is extended. They were not provided to support the longitudinal truss in this face but simply to carry the side wall construction consisting of girts, sheeting and sash above, and concrete block below.

Further consideration of floor economy required that the columns occupy no more room than possible, consequently the crane girders are carried on brackets on the columns and on brackets on the members of the longitudinal trusses between columns. This feature is unusual considering that the crane is a 20-ton unit with 87′-4¾″ span center to center of crane rails. The longitudinal trusses are designed to carry two such cranes as close together as the crane structure will permit and with both cranes loaded to capacity.

Passing now to the specific details of the structure, Fig. 3 shows a sketch of a typical 63′-0″ span truss. These trusses are designed to carry a total vertical load of 50 lbs. per square foot. Two types are used, those at the columns being detailed to secure some stiffness in the connection at these points. Those trusses that frame into the longitudinal trusses are designed merely to transmit load with no special effort made toward fixity at this point.

These trusses have conventional framing and are of usual construction. Tee sections are used for the top chord in order to eliminate gusset plates. End connection plate is butt welded to toe of top chord tee and takes bottom chord angles one on either side. Note the small number of erection holes provided. Two holes on each end of each truss are all that were required. Note, further, that due to the relatively light construction a single V butt is used between the transverse truss and the column or longitudinal truss. The ridge splice is also a single V butt ground off and the splice reinforced by the legs of the center hanger angles. Note at the ridge that for welding the flange of the tee no preparation is necessary, the slope of the member forming with the opposite member sufficient clearance and opening for first class welding.

The 91′-6″ trusses are made in halves in the shop as were the 63′-0″ trusses. There is no essential difference between these larger trusses and the smaller ones already described except as to size.

Fig. 4 shows details of one 41′-6″ panel of the longitudinal truss. This truss has heavy duty to perform in addition to carrying various combinations of crane loadings eccentrically applied. This design requires that the vertical post be heavy enough to take the bending due to the load eccentricity and that the top and bottom chords take the resulting horizontal reactions as a beam. In addition, the system must work as a truss to take the direct stresses from loads

brought in by the transverse trusses. In general, the truss is an ordinary double intersection truss.

Special attention is called to the detail at the vertical truss post in the center of the span. Here, it was necessary to develop a bracket to carry 150,000 lbs. with an eccentricity of 24⅝″. Considerable thought was devoted to this detail and the result is here shown. Inasmuch as the bottom of the crane girder is approximately on the center line of the bottom chord, it was impossible to use a bracket of the same type as is used to support the crane girder for the assembly aisle crane and which is also shown on this sketch. Instead the beam web was cut out on the diagonal line shown and the beam flange bent out to the curve indicated. An irregularly shaped plate 1¼″ thick was then welded in to complete the bracket. This results in a detail fully capable of taking the moments and shears existing. The bent flange connects directly by welding to the crane girder flange and the 1¼″ plate directly to the crane girder web. It was felt, however, that a little additional security should be provided and the crane girder web was slotted to allow a lug or portion of the 1¼″ plate to pass through and weld on the far side. This detail shows the adaptability of welding for solving unusual problems.

Fig. 5 shows a typical detail of two of the columns used in the structure. Column C14 occurs in the line between the pre-assembly aisle and the erection aisle. In order to keep this plane clear for the transfer of material back and forth between the aisles, no sway bracing was here used. The columns, therefore, required lateral stiffness and this is provided by means of 18″ channels welded to the beam flanges. In addition to providing lateral support, the addition of these channels also permits these columns to transmit some portion of the wind load to the foundations.

Referring to Fig. 5 it will be noted that the column details are relatively simple. Two brackets of stiff but not heavy construction carry the crane girder and live loads and transmit them to the column. Immediately above the brackets may be seen the clips for temporarily holding the transverse trusses during erection. These, as may be seen, consist of punched clips plus a seat angle. The weight of the transverse trusses was supported on the seat angle and the columns and trusses were pinned or bolted through the two clips. There will also be noted on the flange of the column four clips of 4″ x ½″ bar each punched. These clips served to hold the longitudinal truss erect but were not intended to take any of the truss dead weight even temporarily. Reference back to Fig. 4 will show that the bottom chord was blocked out at the ends and wedges provided for use until the field welding was complete. These wedges carried the load of the longitudinal truss during erection into the columns through the 4x4 angles indicated in Section E-E, Fig. 5.

Note the welding of the channels to the 24″ CB forming the core of the column. The same procedure is used as is generally specified for riveted struts. That is, continuous welding was used for the bottom 3′-0″ and top 3′-0″ while the welding between consisted of 2″ tacks or welds on 8″ centers. Special continuous welding is also provided in the areas adjacent to the brackets as bracket loads

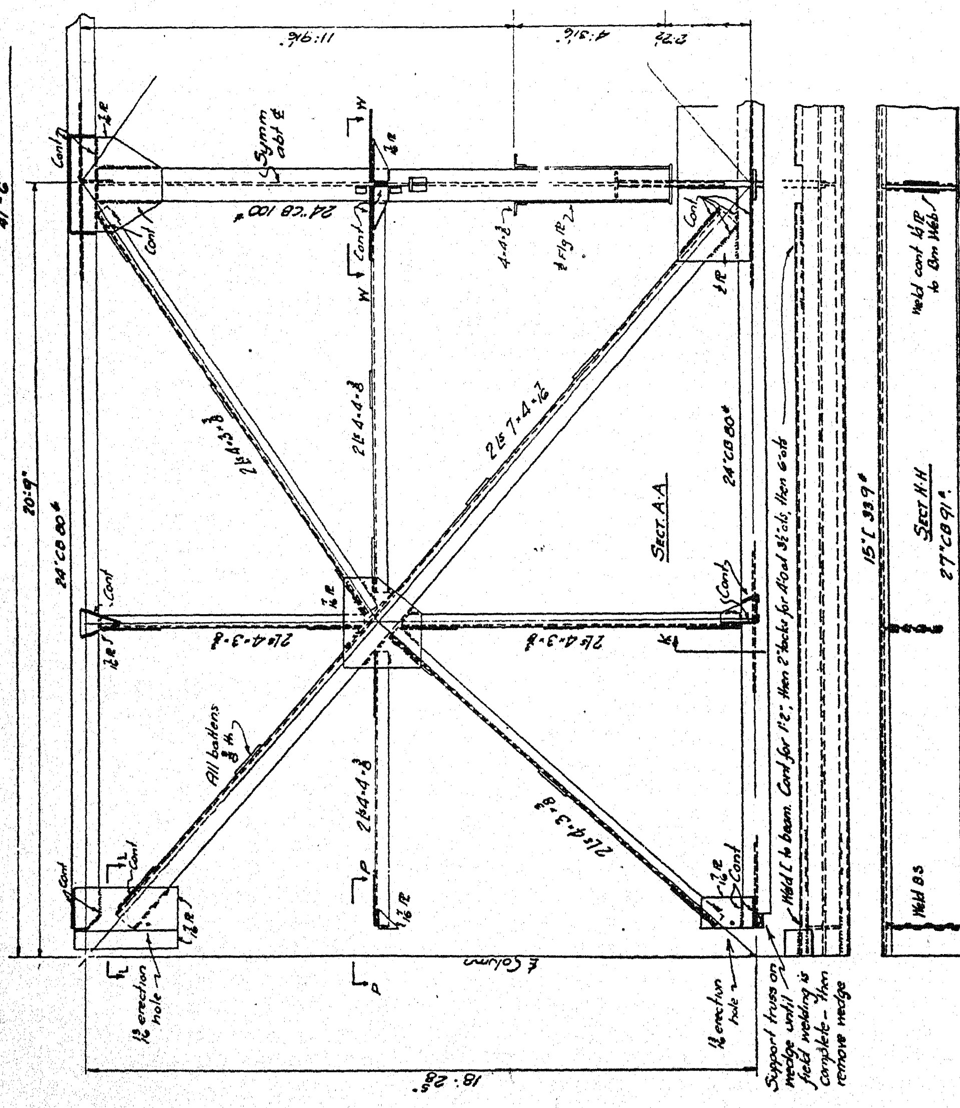


Fig. 4. Details of 41½-foot panel of longitudinal truss. See also page 477b.

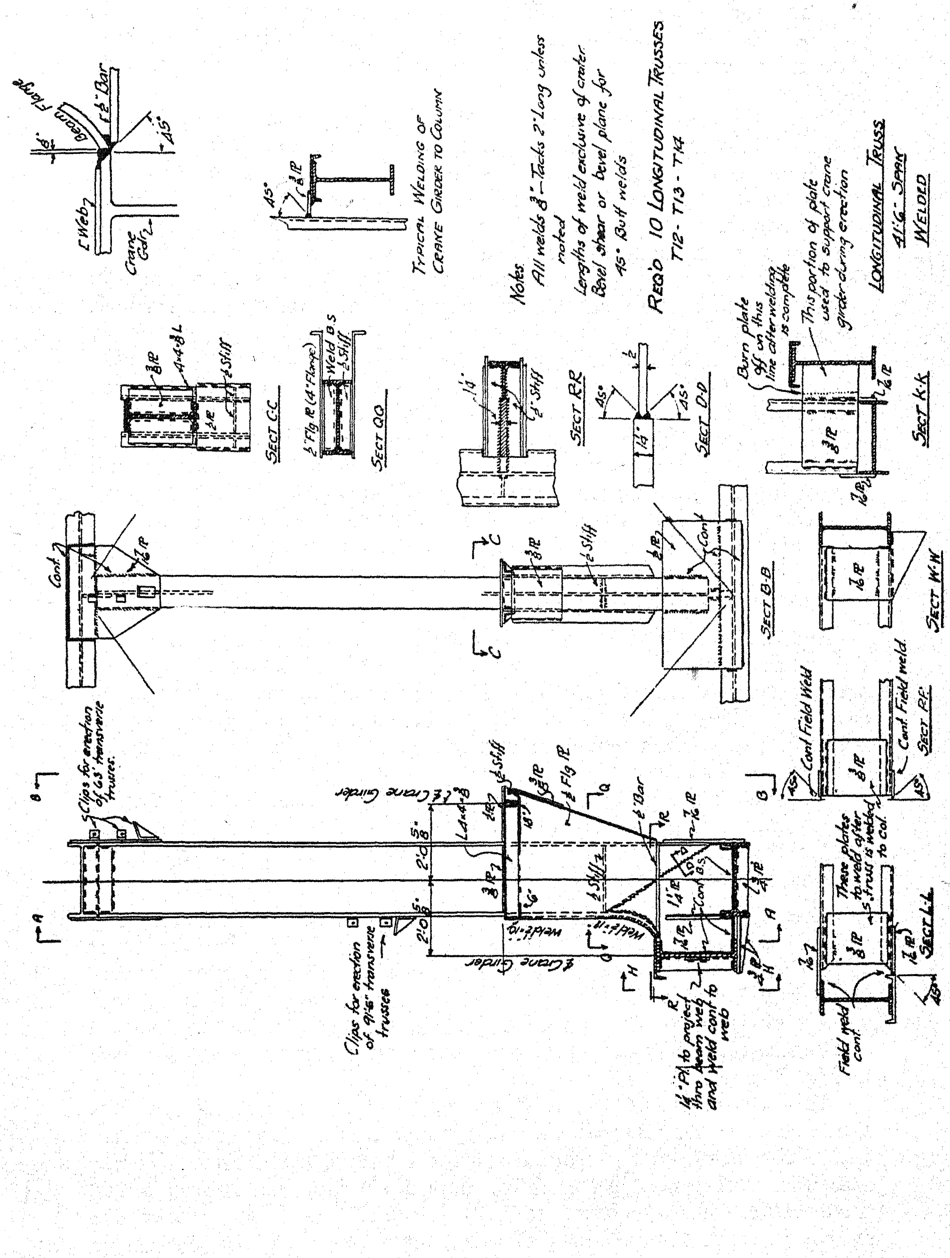


Fig. 4. Details of 41½-foot panel of longitudinal truss. See also page 477a.

must, of necessity, be transmitted first to the channels and thence to the column beam itself.

A simple base detail was used. The bases of the columns were not intended to be fully fixed and so the bolt structure was made relatively low. The columns were milled before welding to the base plate to insure loads being transmitted in bearing rather than through the welds.

Fig. 6 shows miscellaneous sheeting and roof details. The type of detail only is shown here and fastenings are not indicated. All sheeting, insulation, and waterproofing was sublet to a sheeting and roofing contractor and this portion of the work will not be included in the summary of costs. It is interesting to note, however, that welding was employed to fasten the corrugated roofing to the purlins. By use of correct rod and amperage this work was easily and rapidly done. The first effect of the arc was to burn a small hole through the sheeting which was then filled with weld metal. An exceptionally rigid roof was thus obtained and the work was done very rapidly. On the siding, however, this method was not successful and the siding was therefore fastened in place by the usual methods.

Fig. 6 also indicates the general framing of the lean-to. Here, the framing was made to serve two purposes. In addition to forming and supporting the lean-to, this framing was completed and used to serve as special wind bracing to take any transverse wind forces. How it does this is clearly shown. The interior diagonal falls in the office or storeroom partitions and so is not the obstruction which at first glance it might appear to be.

Erection of Building.—The erection of the building framework was carried out by our own forces. All steel was raised by a single crawler type crane except such as was hoisted by hand. The main boom was lengthened sufficiently to lift the highest pieces and in addition a gooseneck outrigger was provided for filling in roof purlins and other light material.

Records of the progress of erection giving specific dates of starting and completing any particular item are not available. The first column was erected early in November and on Feb. 3, 1937 the first barge bottom was laid in the shop.

Cost of Existing Structure.—A summary of costs on items entering into the above structure has been prepared from the detail charges turned in against this work. Fig. 7 shows this summary which covers those items with which we are directly concerned. Subcontract and equipment items are not included nor are items of grading, excavation or foundations. The estimated costs for riveted construction are given in Fig. 8.

Tables A (Figs. 7 & 8), list items for which separate cost returns are available covering material and shop fabrication as distinct from erection while Tables B list other items for which this segregation is not available. Items C show total erection direct labor charges covering the erection of these items for which material and shop labor are shown in Tables A. Tables D are summations of all of the above charges and, therefore, represent the total direct cost of the structure

as previously described, except of course this total does not include sheeting, roofing, sash and similar items nor does it include such erection charges as crane rental, rope blocks or other items of similar nature. It includes no paint or painting. This total further includes no indirect charges such as burden or overhead superintendence, etc.

Comparison of Riveted and Welded Structure.—The following paragraphs cover a comparison of the welded structure and an alternate riveted structure. Before proceeding with the discussion, it appears advisable to clarify the design basis. For the purpose of a proper comparison, it was deemed advisable that the two structures be identical as regards strength and general suitability as possible. Consequently the riveted design is made by following the welded design as closely as possible. An attempt has been made to produce a fair comparative design on which to base any conclusions which may result. Where a connection in the original design might be obviously overwelded, the same riveted connection has been shown with only the proper number of rivets. In general it may be stated that where any disparity exists between the designs, the riveted design has been favored.

In Fig. 9 is shown the riveted alternate for the 63-foot span transverse truss over the pre-assembly aisle shown in Fig. 3. The following statistics are obtained covering each of the designs.

Comparison Welded and Riveted 63-Foot Truss

	Welded	Riveted
Total weight	4067 lbs.	4979 lbs.
Number of pieces requiring some burning operation	6	0
Number of pieces requiring beveling, planing or chipping	4	0
Number of pieces requiring shearing	76	58
Number of pieces requiring punching	24	122
Number of piece-operations	110	180
Number of pieces	106*	122**

*Includes 37 small chips between angles.
**Includes 37 small washers between angles.

	Welded	Riveted
Number of holes to punch	36	948
Number of rivets to drive	0	265
Amount of shop welding	29 linear feet 1/4" fillet	0
	12 linear feet 3/8" fillet	0

Considering the above factors, it appears that the cost of the riveted trusses can conservatively be estimated to be—

For Material	53,747 lbs. x 1.22	66000 lbs. x 1.909	$1260.
For Labor	$392.63 x 1.35		530.
		Total	$1790.

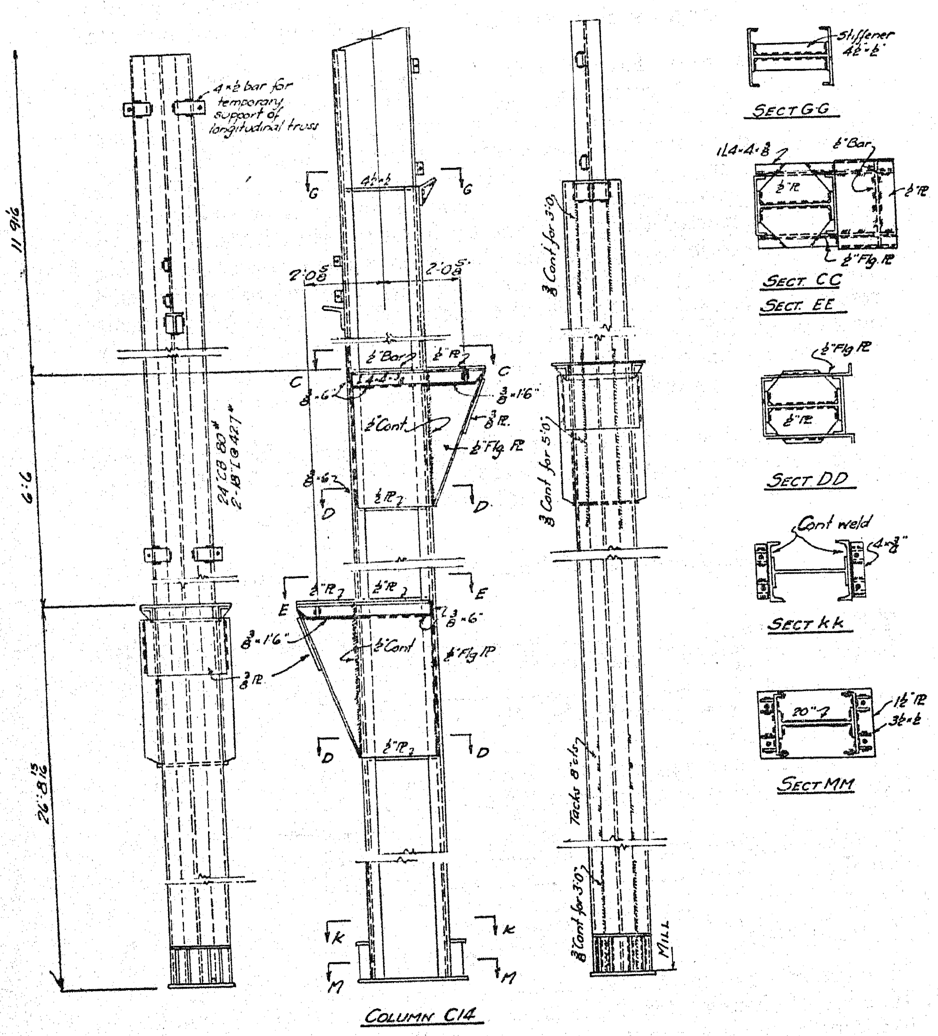


Fig. 5. Typical detail of two columns. See also page 479b.

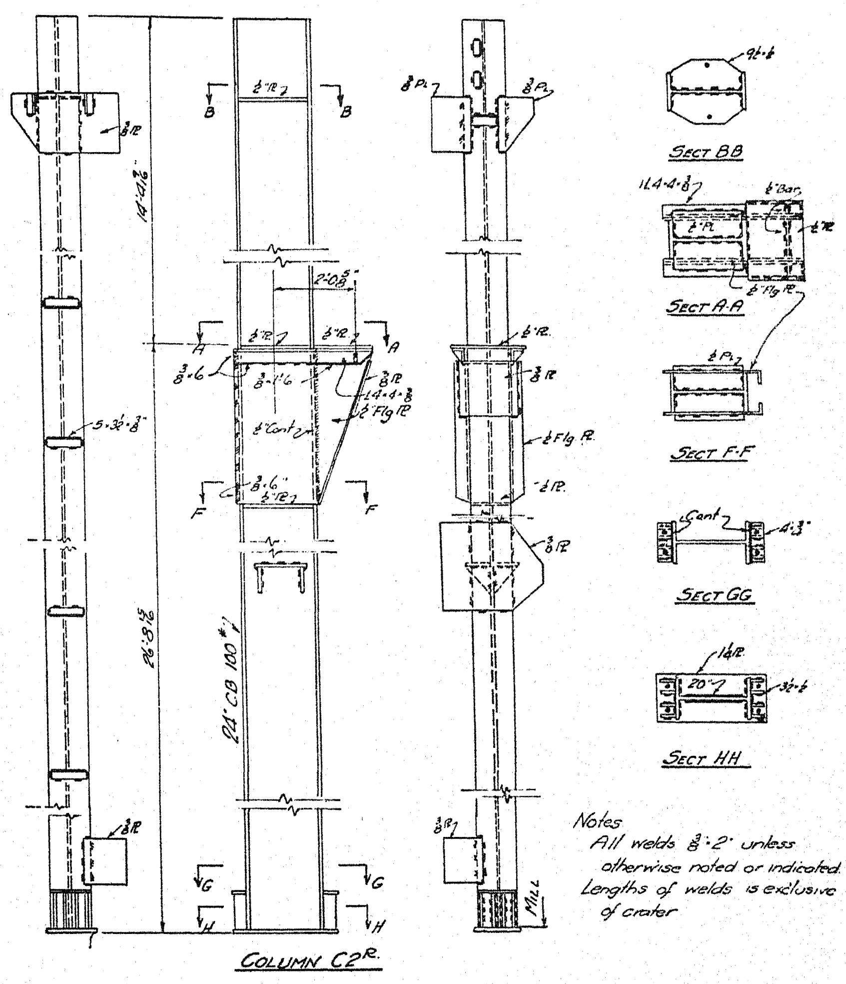


Fig. 5. Typical detail of two columns. See also page 479a.

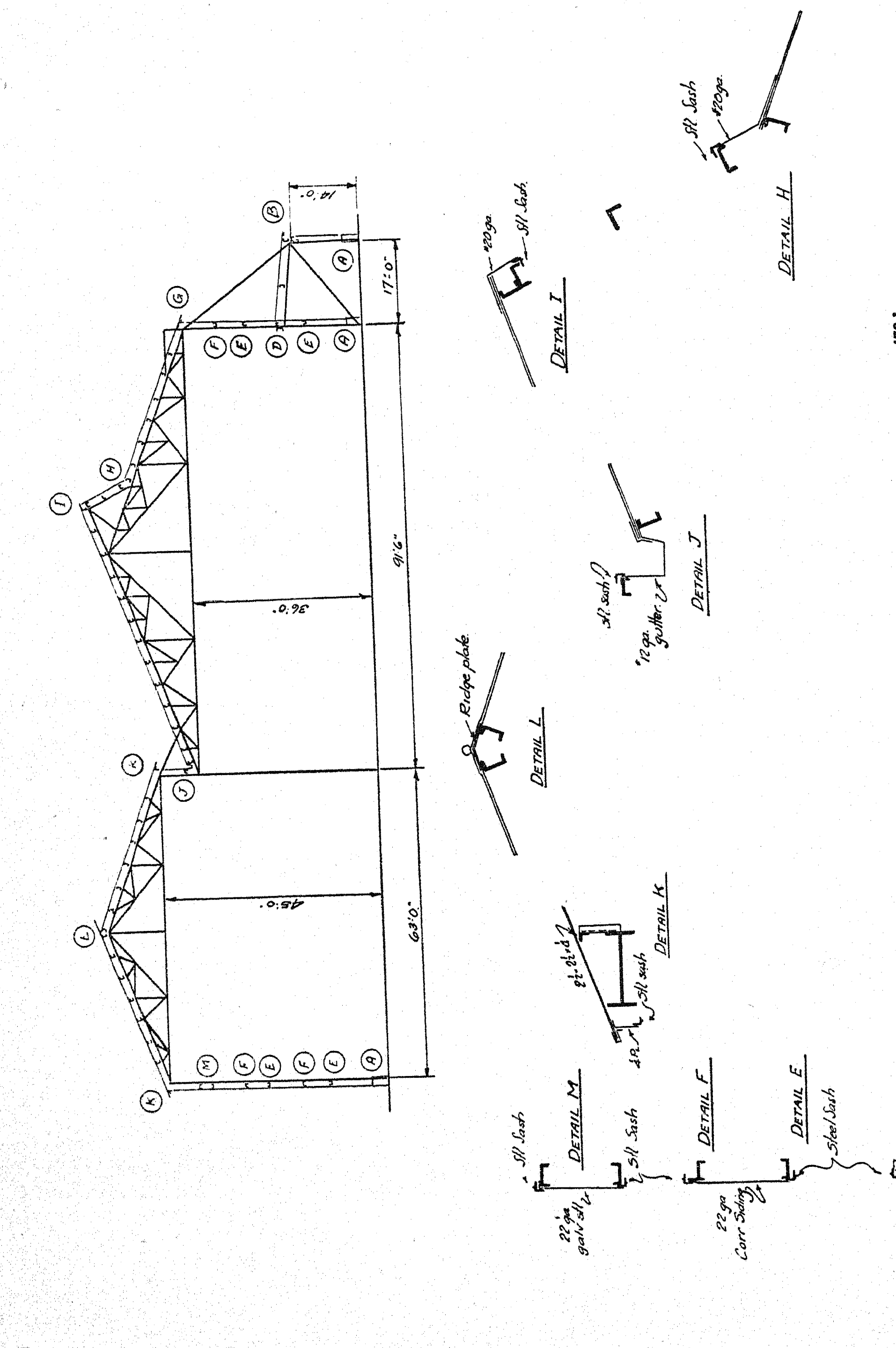
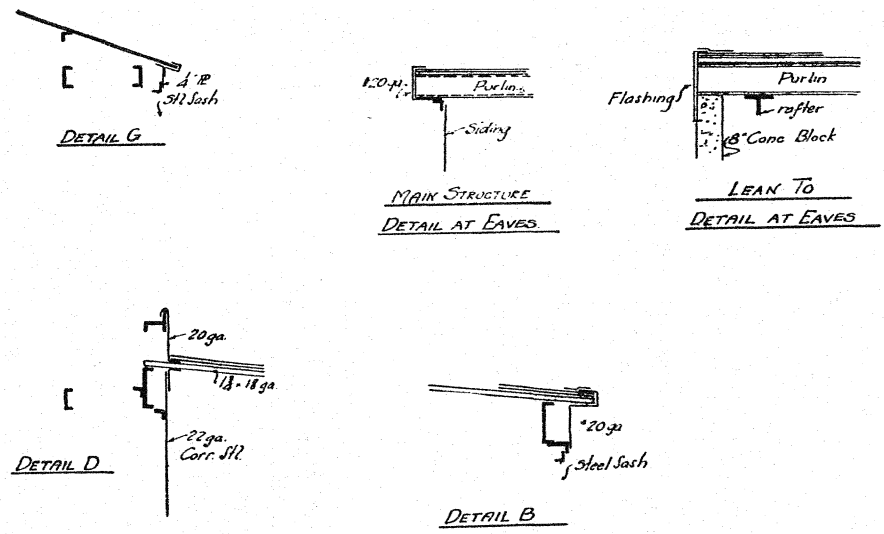


Fig. 6. Miscellaneous sheeting and roof details. See also page 479d.



Roof on main structure consists of 3 ply waterproofing on 2" insulating board - all fastened to and supported by 20 ga corrugated steel.
Roof on lean to consists of 3 ply waterproofing on 2" insulating board all fastened to 18 ga by 1½ deep steel deck.

Fig. 6. Miscellaneous sheeting and roof details. See also page 479c.

TABLE A - COSTS OF ITEMS ENTERING INTO WELDED BUILDING MATERIAL AND DIRECT SHOP FABRICATION LABOR.

Item	Weight	Material Cost	Shop Labor Cost	Cost-cents per lb		
				Mat'l	Labor	Total
Code 26 - Columns	191 231	$3584.82	$943.51	1875	493	2.368
Code 27 - 63' Trusses	53 747	1024.83	392 63	1.909	730	2 639
Code 28 - 91'-6 Trusses including jig.	111 298	2066.78	420.86	1.860	.378	2.238
Code 29 Longitudinal Trusses	167 612	3164.95	1228.05	1.890	732	2 622
Code 30 - Crane Girders	110 712	2042.08	304 60	1 845	275	2 120
Code 31 - Crane Rails & Fastenings	32 581	655 64	16.80	2.010	052	2 062
Code 33 - Purlins	93 185	1641 21	275.77	1.762	296	2 058
Code 34 Girts	41 082	719.93	194 78	1753	475	2.228
Code 35 - Rod Bracing	7 985	174.74	41.28	2 190	517	2 707
Code 37-38 Lat & Sway Bracing	121 205	2182.87	740.06	1.802	611	2.413
Code 39 Hor Door Truss and Brackets	19 431	356.15	200.06	1.835	1.030	2 865
Code 40 Field Bolts	1 800	133.88	—	7.450	—	7 450
Code 41 - Small Door Frames	9 847	177.08	160 51	1 798	1630	3 428
Code 42 Ladders & Walkways	20 676	$451.17	$371 38	2 182	179[illegible]	3.978
Totals and Averages	482,392	$18,376 13	$5240 29	1 872	538	2.410

TABLE B - COSTS OF ADDITIONAL ITEMS - MATERIAL, DIRECT FABRICATION, AND INSTALLATION LABOR.

Item	Weight	Material Cost	Shop & Yard Labor Cost	Cost-cents per lb		
				Mat'l	Labor	Total
Code 45 - Sash Frames	5,810	$104 42	$134 44	1 765	2 315	4 080
Code 46 Hor. Doors - Complete with all fittings	24,472	1265.41	494.31	5.160	2 02	7.180
Code 47 Ver. Doors - Complete with motor & drive	26,637	975 78	611 31	3 660	2 193	5 853
Totals and Averages.	56,919	$2345.61	$1240.06	4.115	2 180	6.295

ITEM C - DIRECT ERECTION LABOR COSTS - ITEMS IN TABLE A

Erect Burn Handle Fit Tack Weld	$5866.89

All costs here shown are exclusive of any burden or other indirect charges, and erection costs do not include charges for equipment materials, tools etc

TABLE D - TOTAL DIRECT MATERIAL AND LABOR COSTS.

Item	Weight	Material Cost	Labor Cost	Cost-cents per lb		
				Mat'l	Labor	Total
From Table A	982,392	$18,376 13	$5290.29	1.872	538	2 410
From Table B	56,919	2,345.61	1240 06	4.115	2.180	6.295
From Item C	—	—	5866.89	—	598	.598
Weld Wire - Yard & Shop	15020	1276.74	—	8 480	—	—
Totals & Averages.	1,054,331	$21998.48	$12397.24	2 085	1.176	3 261

Fig. 7. Summary of costs, arc welded construction.

TABLE A - ESTIMATED COSTS OF ITEMS ENTERING INTO RIVETED BUILDING MATERIAL AND DIRECT SHOP FABRICATION LABOR.

Item	Weight	Material Cost	Shop labor Cost	Cost-cents per lb.		
				Mat'l	Labor	Total
Code 26 - Columns	210,000	$3940	$1370	1.875	.653	2.528
Code 27 - 63' Trusses	66,000	1260	530	1.909	.803	2.710
Code 28 - 91'-6" Trusses	128,000	2380	568	1.860	.444	2.304
Code 29 - Longitudinal Trusses	191,000	3610	1670	1.890	.875	2.765
Code 30 - Crane Girders	114,500	2115	340	1.845	.297	2.140
Code 31 - Crane Rails	32,600	656	17	2.010	.052	2.062
Code 33 - Purlin	93,200	1641	276	1.762	.296	2.058
Code 34 - Girts	41,100	720	195	1.753	.475	2.228
Code 35 - Rod Bracing	8,000	175	41	2.190	.517	2.707
Code 37-38 - Lateral & Sway Bracing	139,000	2500	1036	1.802	.745	2.545
Code 39 - Horizontal Door Truss and brackets	23,300	428	240	1.835	1.035	2.87
Code 40 - Field Bolts	1,800	134	—	7.45	—	7.45
Code 41 - Small Door Frames	11,800	212	193	1.798	1.645	3.443
Code 42 - Ladders & Walkways	21,700	473	520	2.182	2.40	4.582
Totals and Averages	1,082,000	20,244	$6996.	1.870	.646	2.516

TABLE B - ESTIMATED COSTS OF ADDITIONAL ITEMS - MATERIAL, DIRECT FABRICATION AND INSTALLATION LABOR.

Item	Weight	Material Cost	Shop-Yard Labor Cost	Cost-cents per lb		
				Mat'l	Labor	Total
Code 45 - Sash Frames	6500	$ 115	$ 161.	1.765	2.48	4.245
Codes 46-47 Hor. Doors complete with all fittings; Vert. Door complete with motor & drive	51,100	2336	1271	—	—	
Totals and Averages	57,600	$2,451	$1432	-	-	-

ITEM C - ESTIMATED DIRECT ERECTION LABOR COSTS - ITEMS IN TABLE A.

Erect	$6454
Burn	
Handle	
Bolt	
Rivet (& Ream)	

All estimated costs here shown are exclusive of burden or other indirect charges. Erection costs do not include charges for crane equipment tools, etc.

TABLE D - TOTAL ESTIMATED DIRECT MATERIAL AND LABOR COSTS.

Item	Weight	Material Cost	Labor Cost	Cost-cents per lb		
				Mat'l	Labor	Total
From Table A.	1,082,000	$20,244	$ 6996	1.870	.646	2.516
From Table B.	57,600	2451	1432			
From Item C.			6454		.560	.560
Field Rivets	10,000	270				
Totals and Averages	1,149,600	22,965	$14,882	1.998	1.295	3.293

Fig. 8. Summary of costs, riveted construction.

The total direct cost for the riveted trusses is, therefore, $1790 and the unit prices based on the increased weight of 66,000 lbs. are .803c per pound for labor and 2.71c per pound total as compared with $1417.46 total and unit prices of .730c and 2.639c for the welded trusses.

An estimated cost of the 91'-6" transverse trusses in riveted construction is:

Material	111,298 x 1.15 ....128,000 x 1.860	$2380.
Labor	$420.86 x 1.35	568.
		$2948.

The total cost of $2948 shows unit costs of .444c for labor and 2.305c total which compare with $2487.64, .378c, and 2.238c for the welded trusses.

A comparative design in riveting for a longitudinal truss as shown in Fig. 4 will show very little change in main material as the only members which have been increased are the main tension diagonals.

The estimated cost of the riveted longitudinal trusses is:

Material	167,612 x 1.14 ....191,000 x 1.890	$3610.
Labor	$1228.05 x 1.35	1670.
	Total	$5280.

The total cost of $5280 shows unit costs of .875c for labor and 2.765c total which compares with $4393.00, .732c, and 2.622c for the welded trusses.

The estimated cost for the crane girders of riveted design is:

Material	110,712 x 1.035 ....114,500 x 1.845	$2115.
Labor	$17.00 x 20	340.
	Total	$2455.

This total gives unit prices of .297c for labor and 2.14c total as compared with $2346.68, .275c and 2.120c for the welded design.

Fig. 10 shows riveted details for the same two columns as were detailed in Fig. 5. Comparison of these two drawings will show that no changes are made in column sizes but only in detail.

The estimated cost for the riveted columns is:

Material	191,231 x 1.10 ....210,000 x 1.875	$3940.
Labor	$943.51 x 1.45	1370.
	Total	$5310.

This total results in unit prices of .653c for labor and 2.53c total as compared with $4528.33, .493c, and 2.368c for the welded columns.

The estimated cost of the riveted sway bracing is as follows:

Material	121,205 x 1.15 ....139,000 x 1.802	$2500.
Labor	$740.06 x 1.40	1036.
		$3536.

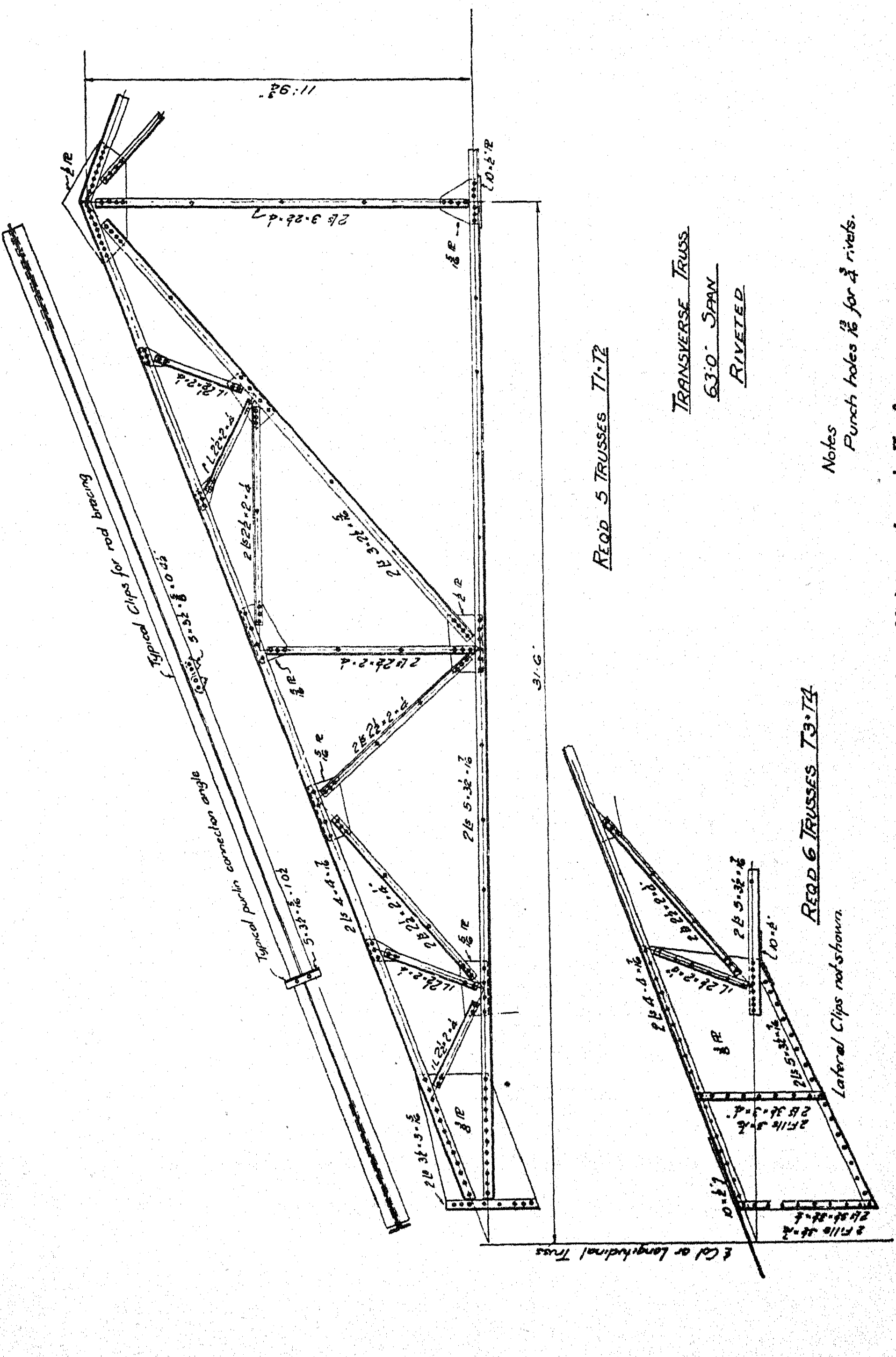


Fig. 9. Riveted alternate for welded truss shown in Fig. 3.

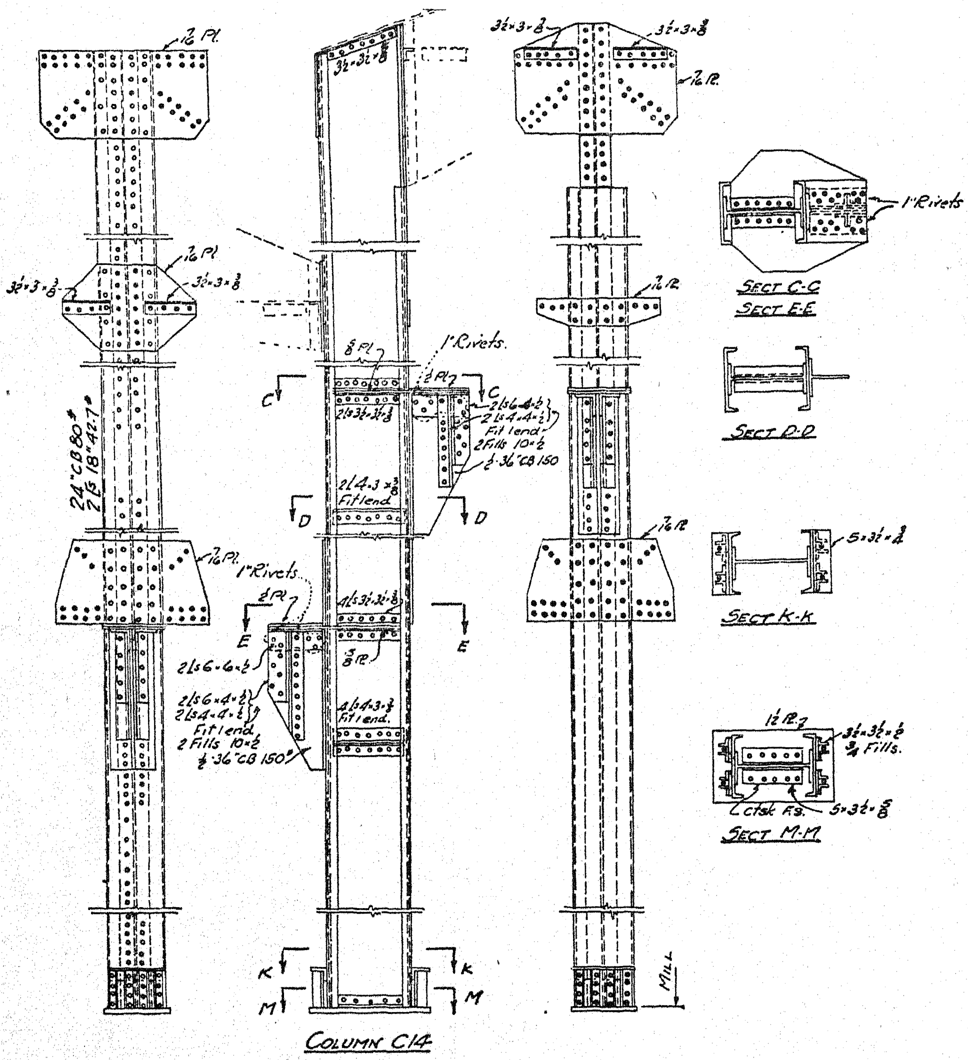


Fig. 10. Riveted alternates for two columns shown in Fig. 5. **See also page 482c.**

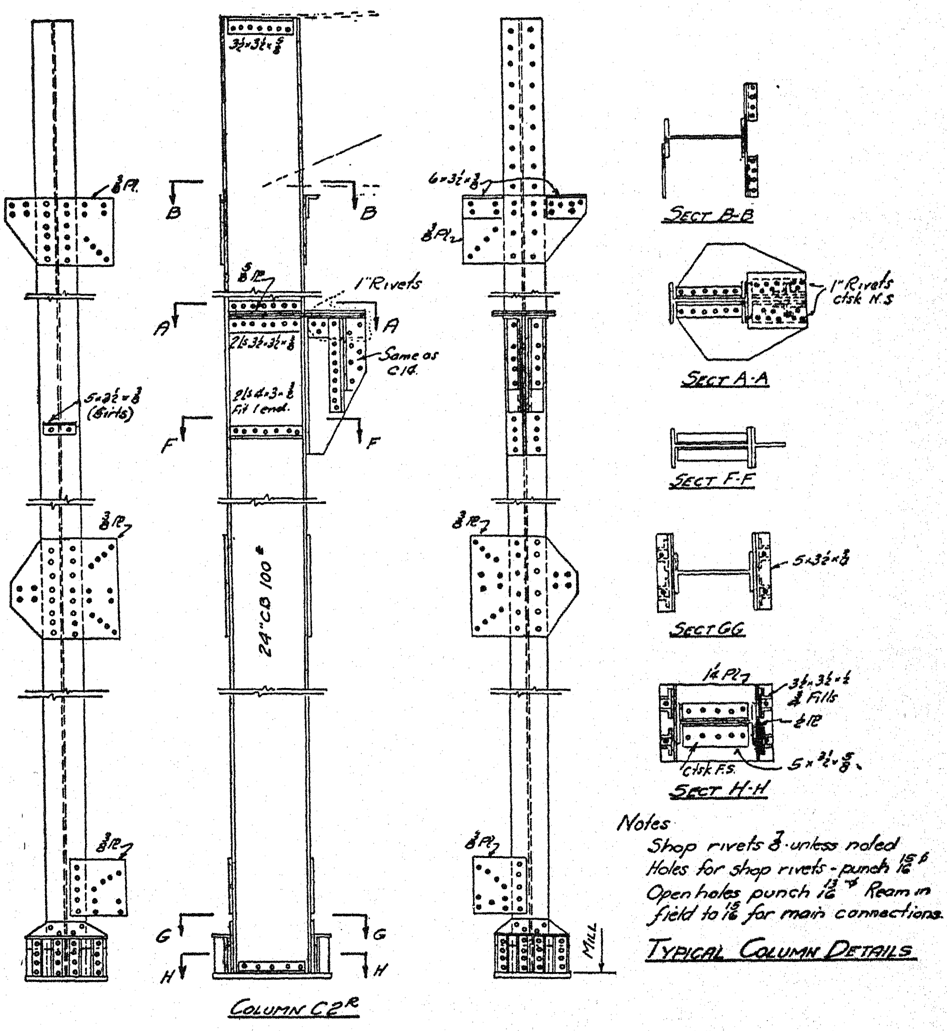


Fig. 10. Riveted alternates for two columns shown in Fig. 5. See also page 482b.

This total results in unit costs of .745c per pound for direct labor only and 2.545c per pound total, these figures comparing with $2932.93, .611c, and 2.413c for the welded design.

Code 39 of the cost sheets, Figs. 7 and 8, covers the horizontal door truss with hangers and brackets. This is a relatively small item and yet one which will show substantial savings for welding.

The truss, as before mentioned, is shallow, being 4′-0″ deep supported from inclined and vertical hangers from the bottom chord of the transverse trusses at the west end of the building. The average panel length is about 4′-6″ and the chords of the truss are composed of 12″ CB Sections at 28 lbs. To rivet this truss would require either increasing the chords to a 10″ CB 49 lbs. to secure a flange width for a 2-rivet connection or the use of a large number of gusset plates on the original chord sections. In the one case, the material would be heavily increased with a moderate increase in labor. In the other case material would be moderately increased but the shop labor would be heavily increased. In either case, hand riveting would be required.

For the purpose of this paper, and remembering this item is a small part of the total, the increase in both material and labor will be taken as 20% giving prices for the riveted truss and hangers as follows:

Material	19,431 x 1.2	23300 x 1.835	$428.
Labor	200.06 x 1.2		$240.
		Total	$628.

This total results in unit prices of 1.03c for labor and 2.865c total for the riveted design as compared with $556.21, 1.03c, and 2.865c for the welded design.

Code 41 covers small door frames with a total weight of 9847 lbs. For items of this kind, the use of welding permits of smooth construction without the use of countersunk rivets and permits of ready attachment to the remainder of the structure by the simplest means. Excess costs for riveting should be comparable to those immediately above.

The last item in Table A is that of ladders, walkaways, and handrailing. This is an item of about 10 tons. The material is extremely light but the use of riveting would not of necessity increase the weight appreciably. Fabrication costs, however, would be increased heavily. For fabrication by welding, it is only necessary to take plain material and weld it together as required. Walkways are, thus, fabricated complete with handrail. For the riveted walkways all material must be punched and the various pieces riveted together usually with only a single rivet at a point. Ladder guards are simply fabricated of strap steel by welding. For this light work the material cost will be increased by 5% while the labor will increase by 40%. We thus have the following estimated costs for riveted ladders, walkways, and handrail:

Material	20676 x 1.05	21700 x 2.182	$473
Labor	$371.38 x 1.40		520.
		Total	$993.

Unit prices from this total are 2.40c for labor and 4.58c total as compared to 1.796c and 3.978c for the welded design.

Codes 46 and 47 cover the horizontal doors on the west end and the vertical door on the east end, and represent a further group of fairly light material items. There are seven of these doors as may be seen in the photograph, Fig. 11.

From our cost analysis sheets, I find that the material cost of $1,265.41 for the horizontal doors is made up of $447.83 for steel

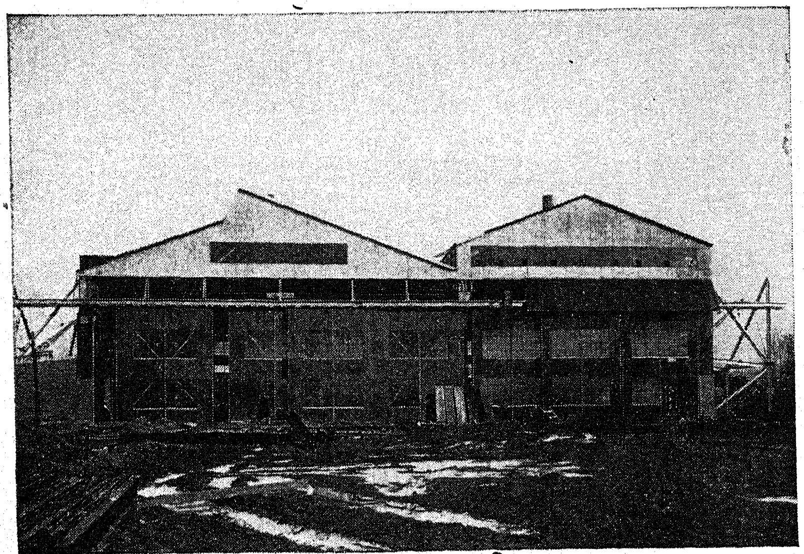


Fig. 11. West end of building showing 7 doors.

plates and shapes and $817.58 for purchased items such as hangers, etc. For the vertical door, these figures are $496.73 for plates and shapes and $479.05 for motors, controls, gears, etc. A percentage of 10% will be applied to the steel, making the estimated material prices:

Cost of Doors—Arc Welded

$447.83 x 1.10	$ 493.
Special items	817.
$496.73 x 1.10	547.
Special items	479.
Total Material	$2,336

In the case of the horizontal doors, the labor charge is $494.31. For the vertical doors, the labor charge is $611.31. In the case of these doors, they were shipped to the site completely knocked down and there assembled prior to erection. So the above charges include the structural shop fabrication, assembly in the yard and erection in the

yard. For this item it is estimated that 15% will be a proper increase for riveted work, making the labor prices as follows:

Cost of Doors—Riveted

$494.31 x 1.15	$ 568.
$611.31 x 1.15	703.
Total Labor	$1,271.
Material	2,336.
Total	$3,607.

It is now necessary to consider the comparative erection costs, this being the figure listed as Item C in Figs. 7 and 8. For this item, even more than the others above, it will be necessary to establish the comparison by a consideration of the amount of work involved rather than by using previous costs.

The erection of the various items will be considered and an attempt made to determine whether or not the work should be done more economically by welding than by riveting, or vice versa.

The work of erection of columns would obviously be the same for both cases.

For the welded longitudinal trusses, these would have to be raised, placed into position and tack welded. While erection holes were provided the foreman would probably not direct that the load be "cut loose" until sufficient tack welding had been placed to insure absolute stability. For the riveted design the load would be held until sufficient bolts or pins were in place. It should be noted that this structure was erected by crews to whom this was a first experience with erection of welded buildings.

I believe, therefore, that the time required for erection of these trusses would be slightly in favor of the riveted design.

The erection of the transverse trusses required not only raising but the preliminary assembly at the site. This was due to being unable to ship these trusses completely fabricated. Each was shipped to the erection site in four pieces as previously described. This assembly was probably done cheaper than it could have been done by riveting. The actual placing of these trusses would require but little more time for tacking than for bolting. I believe the costs involved for erection of these items would be slightly in favor of the welded design.

For the welded design one half of the crane girders was shop assembled to the longitudinal trusses and so erected with them. This procedure would be impractical for the riveted design and therefore the use of riveting would require approximately twice the handling, raising, and fastening. This results in this item favoring materially the welded design.

Purlins, girts, crane rails, and rod bracing will, of course, be the same for both designs.

Lateral and sway bracing require more time for the welded design than would be required for a riveted design. No holes were provided and it was necessary to line up each member in proper position before

welding. For this item, the erection would have been more economical for a riveted design.

All small items not covered in the above classifications should require very little difference in cost of erection. These are in many instances expensive pieces to erect being light but still requiring the use of the crane. In each case, however, it is necessary to have a man aloft to bolt or weld. For the riveted pieces the holes, however, determine the exact location whereas for the welded design it is sometimes necessary to measure or otherwise determine the proper location. If there is any difference involved in these smaller items, it would be in favor of the riveted design.

Recapitulating, there is indicated less expensive erection in the case of the two items, more expensive erection in the case of four items, and equal costs for five items, when considering the welded structure.

There is now left only the item of permanent fastening of the erected items. Any appreciable difference must show up here if any measure of cost difference either way is to be obtained. In the case of the welded structure, the time previously lost has resulted in most cases at least in permanently fixing the location of pieces in position so that the structure is now ready for welding. Proper detailing has resulted in at least the greater part of the welds being made in the down position. As a result, little scaffolding is required and, for many points, none at all.

For the riveting, four-man gangs are required. In addition, the work must be well bolted up and all main connections must be reamed prior to driving the rivets.

Scaffolding is required at almost all points and this must be of a more substantial nature than for the use of a welder. These items represent appreciable cost due to the large number of points which would have to be riveted and the small number of rivets in each point.

For welding, the work of joining must be done following blueprint as there is no mark on the steel indicating the length, location and size of welds. On the other hand the rivet heater has to measure the depth of holes at each point to determine the number and length of rivets to be heated.

I believe this part of the erection shows considerable economy in favor of welding on a structure of this type with so many points requiring joining but with only a small amount of work required at any one point. The welder can get to the point and complete his work quickly.

The actual evaluation of comparative erection costs is difficult but I believe an increased cost of from 10% to 20% would result if the building were riveted. The lower value of 10% is used in the table of comparative costs.

Fig. 8 shows a summary of the costs from a riveted design. Referring to this table, we note this design has a total weight of 575 tons and a total direct labor and material cost of $37,847, resulting in a final direct labor and material cost of $66.00 per ton for the steel erected. For comparison, the welded design had a total tonnage of 527, a cost of $34,395 and a cost per ton of $65. This shows a conservative excess

cost for the riveted design of $3452 or 10%. Or putting it the other way, by the use of welding, we have saved 10% on the direct costs. This saving is made up of a saving of 4.4% in material cost and 21.7% in labor cost.

It must be borne in mind that these savings do not begin to represent the entire actual saving. Further savings result all along the line. In the drawing room, drawings are made cheaper, the drawing room burden or overhead is proportionately lower for welded work. In the template shop, fewer templates must be made with correspondingly less cost and the template burden is reduced. It is not the function of this paper to discuss the amount, nature, or propriety of our burden charges. However, it may be of interest to show the nature of the savings based on an assumed average burden or other charges with this percentage applied to the labor only.

With 25% burden.

	Welded Design	Riveted Design	
Material	$21,998	$22,965	excess 4.4%
Labor	12,397	14,882	excess 21.7%
25% burden	3,099	3,720	excess 21.7%
	$37,494	$41,567	

Excess for riveted design 10.9% or $4,073.

With 50% burden.

	Welded Design	Riveted Design	
Material	$21,998	$22,965	excess 4.4%
Labor	12,397	14,882	excess 21.7%
50% burden	6,199	7,441	excess 21.7%
	$40,594	$45,288	

Excess for riveted design 11.5% or $4,694.

With 75% burden.

	Welded Design	Riveted Design	
Material	$21,998	$22,965	excess 4.4%
Labor	12,397	14,882	excess 21.7%
75% burden	9,298	11,162	excess 21.7%
	$43,693	$49,009	

Excess for riveted design 12.2% or $5316

With 100% burden.

	Welded Design	Riveted Design	
Material	$21,998	$22,965	excess 4.4%
Labor	12,397	14,882	excess 21.7%
100% burden	12,397	14,882	excess 21.7%
	$46,792	$52,729	

Excess for riveted design 12.7% or $5,937.

The above tabulation indicates a variation of saving from 10% to 12.7% or from $3,452 to $5,937, for direct charges plus burden

varying from 0% to 100% if the welded design is used as compared to the riveted design. It will be fair to state that we have saved 12½% or approximately one-eighth in cost by erecting a welded structure.

The above statement is then the substantiation of the first premise made before the design was worked up, that is, the welded design would be more economical.

The second premise—that of time saved—cannot be substantiated by the facts presented. The work could not be continuously prosecuted. In the drawing room and shops, the work had to be done concurrently with other work. The same diversions occurred in the field. No records were set up either in the fabrication or erection of the structure. However, it seems reasonable that, in general, work and time would be saved if material and labor were saved. This is further brought out by realizing:

1. Drawings can be made more rapidly and this gets the details to the shop more rapidly.
2. Fewer templates are required so that production can get under way sooner.
3. Actual shop production should be faster as smaller tonnage, fewer pieces and less fabrication is required.
4. Erection should take no longer.

The third premise—structural suitability—appears to be well borne out. The structure is firm, sound, and free from vibration. Welding has done all that rivets could do and more. Some details are felt to be superior to the riveted counterpart and the rigidity in general is increased by the use of welding.

As to the fourth and final premise—a permanent exhibit of welded work—here it is. The structure has been viewed by many acquaintances in business as well as prospective customers and has played no little part as an addition to our sales force.

Conclusion.—In conclusion I might say that the decision to attempt to establish a comparison between an actual fact and a mythical structure was undertaken with some misgivings. An alternative method of approach was considered—that of preparing an estimate for a riveted structure as would be done for any bid which we might make to an outside customer.

The type of building with wide column spacing and special provisions for wind bracing, together with unusual doors for full end openings would dictate higher costs than for standard mill buildings. An accurate cost estimate for riveted construction would require a detailed analysis. It is submitted that the comparative method used is the more comprehensive. Therefore, it was decided to attempt to visualize the comparative amounts of work which had to be performed on the various items necessary to produce a completed structure. If the picture has been presented properly, the savings should be evident.

Chapter IV—Radical Departure in the Construction of Large Roofs

By R. Sherman,
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Large roofs figure prominently in the design and construction of a very wide field of modern buildings. Examples may be quoted in railway termini, theatres, garages, stadia, swimming pools, grandstands, aeroplane hangers, school and hospital halls, and single-story factory buildings.

As a typical example for any of the above, a detailed description follows of a single-story factory building erected in 1937-8, which embodies in its design a roof which is entirely novel in its method of construction. (See Fig. 1.)

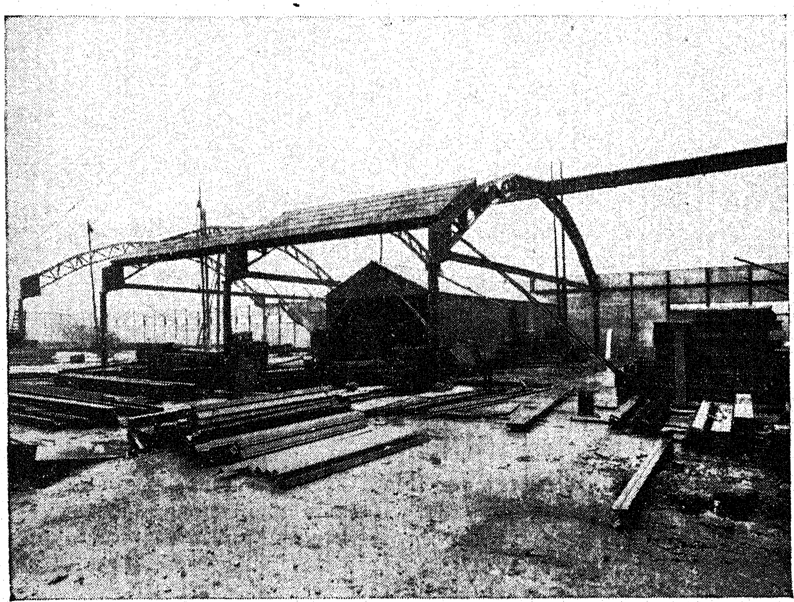


Fig. 1. Application of roof to factory building.

Although special qualities were required for the walls and roofing material for this factory, the construction of the roof itself may be varied in type and span to suit any of the above structures, and give a roof, the cost and the structural weight of which will prove to be low when compared to those built in accordance with existing methods.

The single-story factory building is perhaps the most widely used of all commercial structures. Where the cost of ground space is not

of primary importance, the obvious advantages of this type of building nearly always preclude the selection, rightly, of any other design.

Factory buildings in general are designed on one of the following lines:—

a) With the object of keeping down initial cost.
b) Keeping initial cost in mind, but also with some thought as to the purpose to which the building is to be put, and
c) From the point of view of obtaining the structure most suited to its intended purpose.

Unfortunately, economy is, even now, too often the main consideration, efficiency and utility being forced to take minor places in the mind of the designer. The roof structure and the roofing material account for a large proportion of the cost of a factory of the single-story type.

As a roof which is to have good properties must necessarily be heavier than simply a protection from the weather, it follows that the members carrying such a roof will be proportionately heavier, and this increase in weight will be carried down through the columns and so down to the foundations. This paper proposes to show how a building was designed from the standpoints first of all of utility, efficiency and qualities of walls and roofing, and yet produced a structure costing less than the normal type designed on the "economy first" principle.

Naturally, such a design had to be fundamentally different from the accepted standards for this type of construction, and this difference was achieved by the adoption of these three main points:

1. The rejection of rolled steel sections as being unwieldy, unsuitable and uneconomical.
2. The replacement of rolled steel sections by sections made of one-eighth inch thick mild steel plate, folded to simple shapes as required, and
3. The use of electric arc welding for the fabrication of the separate units of folded plates, first to make up the sections required, and then to connect up these sections to form the composite structure.

Arc welding was chosen for this work as being the best and only practicable method of making the joints and connections required.

The factory was intended to house plant and machinery for folding flat steel sheets of light gauge to give a dovetail section, these sheets afterwards being made up into walls, ceilings, roof units, etc. Provision had to be made for installing later much larger pieces of machinery, and this meant that the lower steelwork, such as chords, ties and the like had to be kept down in size as much as possible. Even more important, it was stipulated that the factory should have very good heat and sound insulating properties, and should also have a comparatively large area of natural roof lighting. To obtain these ends, the roof was made of "Lewis" dovetail roof units, and the walls of double "Lewis" dovetail sheets.

These roof units consist of parallel dovetailed metal sheets five-eighths of an inch deep over the flutes, of 24-gauge metal sheet, and

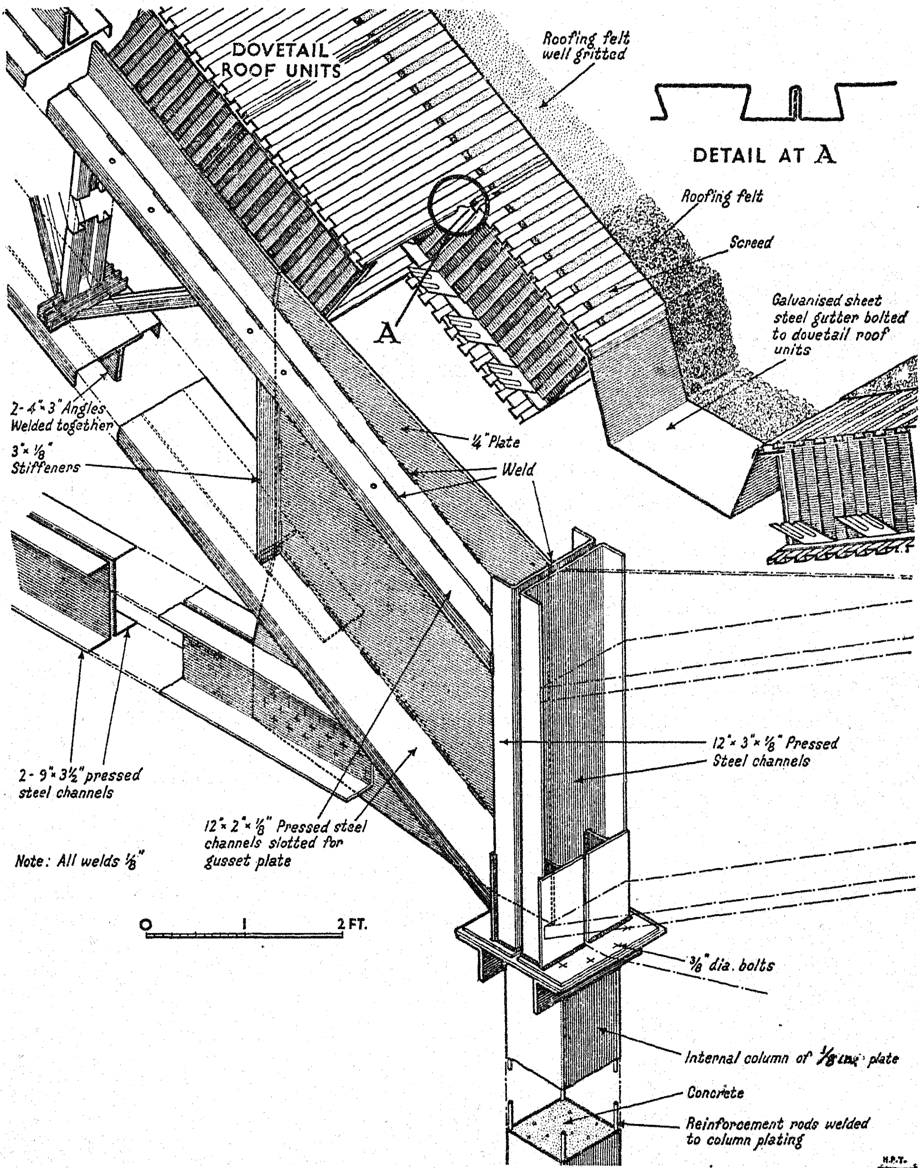


Fig. 2. Isometric view of heel of arch truss showing constructional details.

with a clear air-space of 15″ between the sheets. These units are made up in standard widths of 2 feet, spanning over 30 feet, and are fabricated complete ready for erection. The finish to the roof was 2″ of concrete screed, one layer bitumen felt, one layer of bitumen and a top dressing of pebble. The walls consisted of 2 similar dovetailed sheets, with a 6″ air gap, finished with one inch of plaster internally and 2″ externally. These constructional details are shown in Fig. 2.

The heat and sound insulating properties of such a construction will be apparent, and in practice have fully realized expectations.

Continuous panels of glazing approximately 10′ wide were provided, giving a natural light area of about 30% of the roof area.

The total dead weight of the roof on the roofing units was 35 lbs. per square foot, excluding arches, purlins and other steelwork. Although this is high compared to more usual roofing materials (e.g. corrugated asbestos or iron), the weight of the steelwork in the roof proved to be 20% to 40% lighter than would have been required for a roof of asbestos or iron sheet, supported by ordinary rolled steel members.

Design.—The area covered by the building was 72,000 square feet, being made up of 5 bays of 60′ width each 240′ long. An idea of the principle of the arrangement will be obtained from Fig. 1, which is a photograph taken during erection. The arches, at 30′ centres span 60′, thus giving one internal column for 1,800 super feet of floor space.

The static design of the structure was conventional, and may be summarized as follows:

3-hinged arches of trussed construction, of 60′ span and at 30′ centres are carried on columns designed to take the vertical reactions only. The horizontal thrust in the arch members is taken in tie bars, and the wind load is taken by a horizontal beam in the walls carried at intervals on stiff columns.

Following are the calculations for the loads in the members, and also the design of the various members themselves.

Notation.

w = uniformly distributed load; W = concentrated load; M = bending moment; H = horizontal thrust; R or V = Vertical reaction; D.L. = abbreviation for dead load; L.L. = abbreviation for live load; A = area of section; I = moment of inertia of section; g = least radius of gyration of section; l = effective length of compression member; z = modulus of section; f = stress.

Arch ribs, Loads on roof:—

Dovetail units, screed and finish	35 lbs:/ft:²
Glass	5
Live load	15
Self-weight of arch rib	40 lbs:/ft:

Load on arch:—

Fully loaded on units = 30 x (35 + 15) + 40	= 1,540 lbs:/ft.
Fully loaded on glass = 30 x (5 + 15) + 40	= 640
Half live load on units = 30 x (35 + 7.5) + 40	= 1,315
Half live load on glass = 30 x (5 + 7.5) + 40	= 415

Case 1.

Fully loaded both sides. (See Fig. 3).

$$w_1 = \frac{4.0}{2} \times 1540 = 3080 \text{ lbs.}$$

$$w_2 = \frac{8.3}{2} \times 1540 = 6400$$

$$w_3 = \frac{8.3}{2} \times 1540 = 6400$$

$$w_4 = \left(\frac{4.0}{2} \times 1540\right) + \left(\frac{10}{2} \times 640\right) = 6280$$

$$w_5 = \left(\frac{10}{2} \times 640\right) + \left(\frac{2.2}{2} \times 1540\right) = 4890$$

$$w_6 = \frac{6.2}{2} \times 1540 = 4770$$

$$w_7 = \frac{6.0}{2} \times 1540 = 4620$$

$$w_8 = \frac{4.2}{2} \times 1540 = 3240$$

$$R = \underline{39{,}680} \text{ lbs.}$$

M at hinge = 39,680 x 30 = 119,040

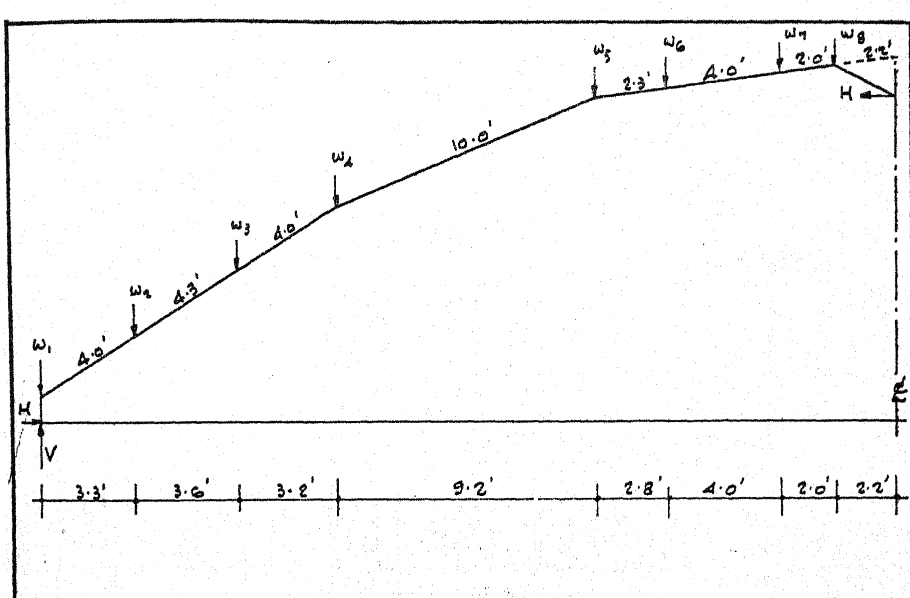


Fig. 3. Load diagram for Case 1.

$$
\begin{aligned}
-\ 3080 \times 30 &= 92{,}400 \\
-\ 6400 \times 26.7 &= 171{,}000 \\
-\ 6400 \times 23.1 &= 148{,}000 \\
-\ 6280 \times 19.6 &= 123{,}000 \\
-\ 4890 \times 10.4 &= 50{,}900 \\
-\ 4770 \times 8.2 &= 39{,}200 \\
-\ 4620 \times 4.2 &= 19{,}400 \\
-\ 3240 \times 2.2 &= 7{,}100 \\
\hline
& \quad 651{,}000 \\
\hline
M &= 468{,}040 \text{ Lb.-ft.}
\end{aligned}
$$

$$H = \frac{468{,}040}{12} = 39{,}000 \text{ lbs.}$$

Case 2.

Fully loaded one side. D.L. ± ½ L.L. other side. (See Fig. 4).
w_1 to w_8 as Case 1.

$$w_9 = \frac{4.2 \times 1315}{2} = 2670 \text{ lbs.}$$

$$w_{10} = \frac{6.0 \times 1315}{2} = 3950$$

$$w_{11} = \frac{6.2 \times 1315}{2} = 4080$$

$$w_{12} = \frac{(10 \times 415)}{2} + \frac{(22 \times 1315)}{2} = 3620$$

$$w_{13} = \frac{(4.0 \times 1315)}{2} + \frac{(10 \times 415)}{2} = 4840$$

$$w_{14} = \frac{8.3 \times 1315}{2} = 5450$$

$$w_{15} = \frac{8.3 \times 1315}{2} = 5450$$

$$w_{16} = \frac{4.0 \times 1315}{2} = 2670$$

Reactions.

$$
\begin{aligned}
V_A \times 60 &= \\
5450 \times 3.3 &= 18{,}000 \text{ lbs.} \\
5450 \times 6.9 &= 37{,}600 \\
4840 \times 10.4 &= 50{,}200 \\
3620 \times 19.6 &= 71{,}000 \\
4080 \times 21.8 &= 89{,}000 \\
3950 \times 25.8 &= 102{,}000 \\
2760 \times 27.8 &= 76{,}900 \\
3240 \times 32.2 &= 104{,}500 \\
4620 \times 34.2 &= 158{,}000 \\
4770 \times 38.2 &= 182{,}000 \\
4890 \times 40.4 &= 198{,}000 \\
6280 \times 49.6 &= 312{,}000 \\
6400 \times 53.1 &= 340{,}000 \\
6400 \times 56.7 &= 363{,}000 \\
3080 \times 60.0 &= 185{,}000 \\
\hline
& \quad 2{,}287{,}200
\end{aligned}
$$

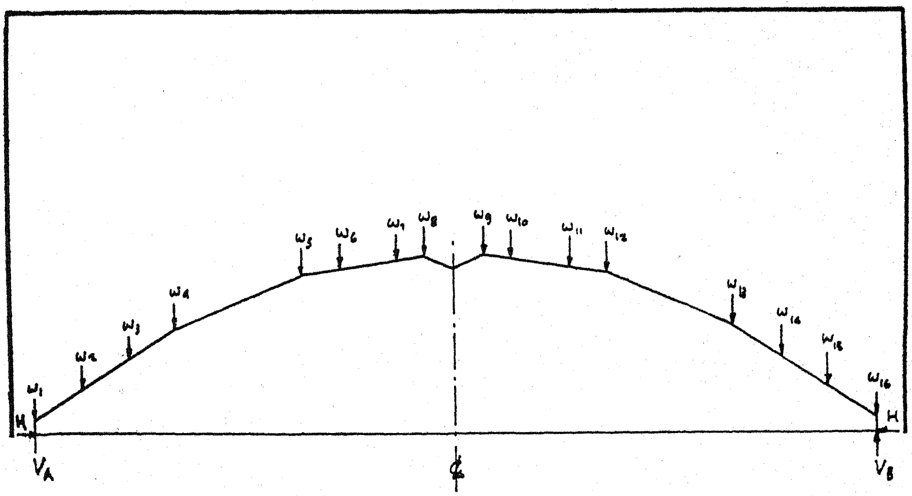


Fig. 4. Load diagram for Case 2.

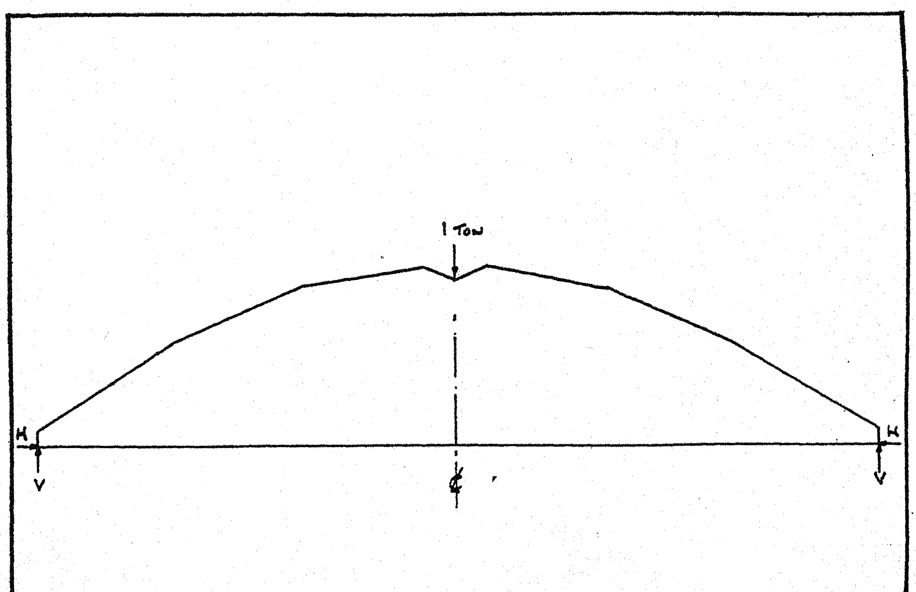


Fig. 5. Load diagram for crane.

$$V_A = \frac{2{,}287{,}200}{60} = 38{,}200 \text{ lbs.}$$

V_B = 39,680
2,670
5,450
5,450
4,840
3,620
4,080
3,950
2,760 — 38,200 = 34,300 lbs.

M at centre hinge =
(38,200 x 30) — 651,000
= 1,146,000 — 651,000 = 495,000 lbs. ft.

$$H = \frac{495{,}000}{12} = 41{,}250 \text{ lbs.}$$

Shear at hinge =
39,680 — 38,200 = 1,480 lbs.

Crane Load. (Note: The crane refers to a travelling crane in each bay, moving along a line through the apex of the arches.) (See Fig. 5).

$V_A = V_B = 1120$ lbs.
$M = 1120 \times 30 = 3{,}360$ lbs. ft.

$$H = \frac{3360}{12} = 2{,}800 \text{ lbs.}$$

Fig. 6 shows a typical space-load diagram, from which is obtained the loading in the members of the arch.

Top Chord of Arch.—Properties of section. (See Fig. 7).

$$I_{xx} = \frac{2 \times \frac{1}{8} \times 4^3}{12} + \frac{2 \times 3.88 \times \frac{1}{8}^3}{12} + \frac{12 \times \frac{1}{8}^3}{12} + \frac{2 \times \frac{1}{8} \times 3.88^3}{12}$$

$$+ 2 \times 4 \times \tfrac{1}{8} \times 1.63^2 + 2 \times 4 \times \tfrac{1}{8} \times 0.313$$
$$+ 12 \times \tfrac{1}{8} \times 0.438^2 + 2 \times 2 \times \tfrac{1}{8} \times 1.38$$
$$= 1.33 + 0 + 0 + 1.21 + 2.64 + 0.0975 + 0.28 + 0.946$$
$$= 6.5035''^4$$

$$g_{xx} = \sqrt{\frac{6.5035}{3.94}} = 1.285''$$

$$I_{yy} = \frac{\frac{1}{8} \times 12^3}{12} + 2 \times 2 \times \tfrac{1}{8} \times 6^2 + \frac{\frac{1}{8} \times 8^3}{12} + \frac{4 \times \frac{1}{4}^3}{12}$$

$$= 18 + 18 + 5.3 + 0$$
$$= 41.3''^4$$

$$g_{yy} = \sqrt{\frac{41.3}{3.94}} = 3.25''$$

Bottom Chord of Arch.
Properties of Section.
(See Fig. 8).

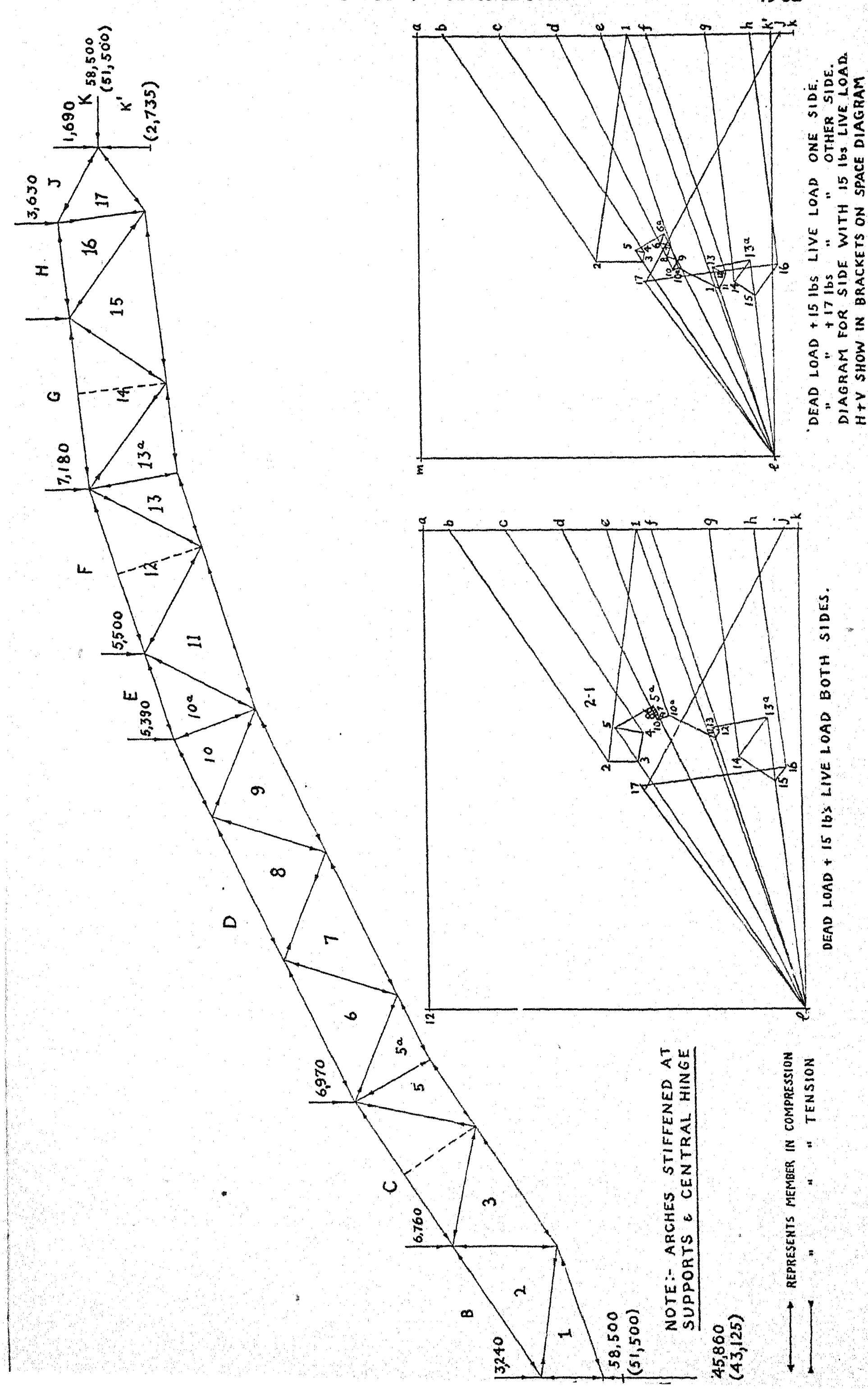


Fig. 6. Typical space-load diagram.

$$I_{xx} = 11.75 \times \tfrac{1}{8} \times 0.6745^2 + \frac{\tfrac{1}{4} \times 7^3}{12} + 2 \times \tfrac{1}{4} \times 0.263^2$$

$$+ 7.75 \times \tfrac{1}{8} \times 0.5495^2 + \frac{4 \times \tfrac{1}{4}^3}{12} + 4 \times \tfrac{1}{4} \times 1.388^2$$

$$= 0.688 + 0.167 + 0.0346 + 0.292 + 0 + 1.925$$
$$= 3.088''^4$$

$$g_{xx} = \sqrt{\frac{3.088}{3.94}} = 0.885''$$

$$g_{yy} = 3.24''$$

Top chord.

Maximum $\dfrac{l}{g} = \dfrac{4 \times 12}{1.285} = 37.4$

Maximum allowable stress $= 6.68$ ton/$''^2$

Greatest direct stress $= \dfrac{32{,}000}{3.94 \times 2240} = 3.6$ ton/$''^2$

Bending moment $= \dfrac{1540 \times 4^2}{8} = 3080$ lb.:–ft.

z of section $= \dfrac{6.5035}{3.625} = 1.8''^3$

Bending stress $= \dfrac{3080 \times 12}{2240 \times 1.8} = 9.16$ ton/$''^2$

Perpendicular struts will be introduced under the centre of the spans to take this bending stress.

Bottom chord.

Maximum $\dfrac{l}{g} = \dfrac{4 \times 12}{0.885} = 54.$

Maximum allowable stress $= 6.14$ ton/$''^2$

Greatest direct stress $= \dfrac{49{,}200}{3.94 \times 2240} = 5.66$ ton/$^{2''}$

Diagonals.

For the lightly loaded diagonal arch members, 16-gauge sheet folded as shown in Fig. 9 was used.

Area $= (5 + 7) \times 1/16 = 0.75''^2$

$$I_{xx} = \frac{4 \times 1/16 \times 1.25^3}{12} + 6 \times 1/16 \times 0.6^2$$

$$= 0.056 + 0.164 = 0.2146''^4$$

$$g_{xx} = \sqrt{\frac{0.2146}{0.75}} = 0.535''$$

Maximum $= \dfrac{3 \times 12}{0.535} = 67.$

Maximum allowable stress $= 5.55$ ton/$''^2$

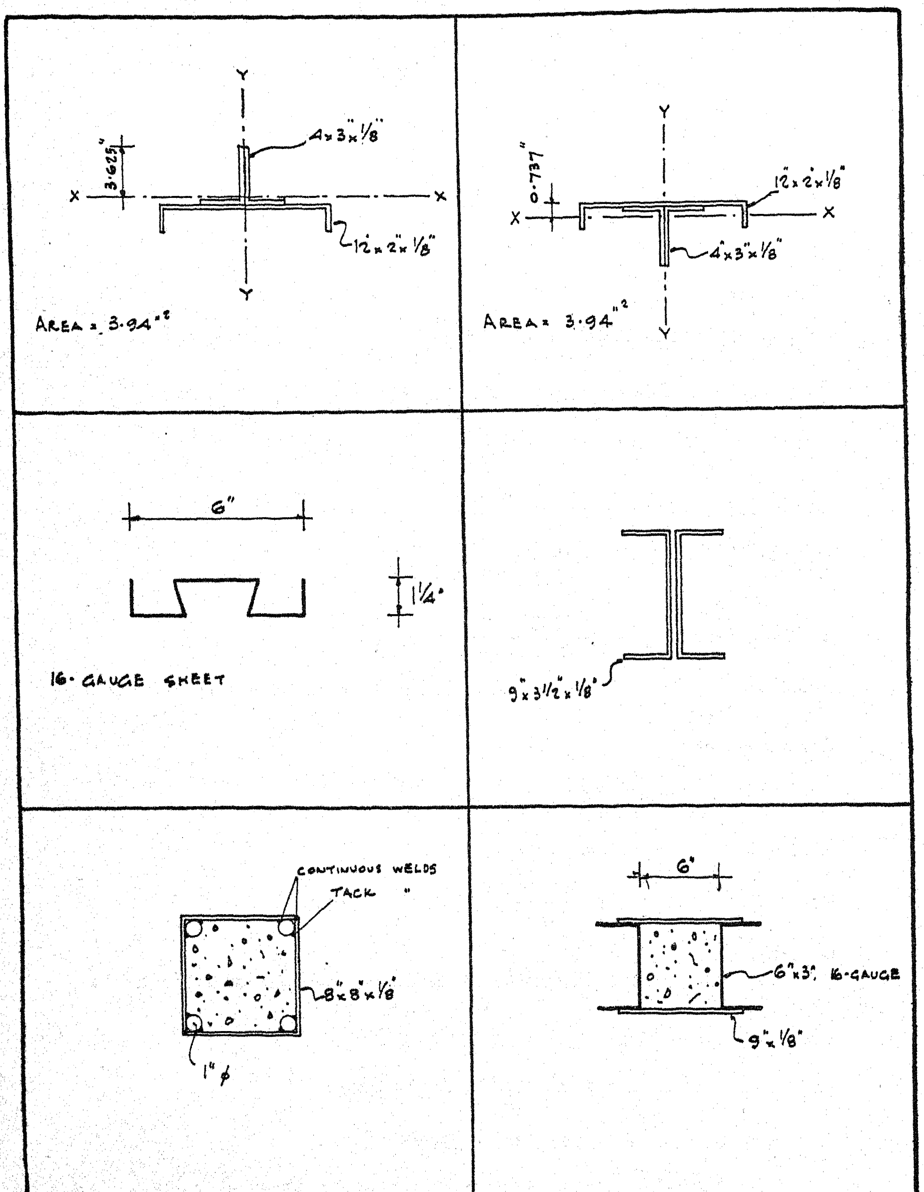


Fig. 7, (upper left)—top chord of arch truss. Fig. 8, (upper right)—lower chord of arch truss. Fig. 9, (center left)—diagonal member of arch truss. Fig. 10, (center right)—tie member of arch truss. Fig. 11, (lower left)—internal column. Fig. 12, (lower right)—structural wall column.

Maximum direct stress $= \dfrac{8500}{0.75 \times 2240} = 5.05$ ton/"^{2}

Greatest tension $= \dfrac{6900}{0.75 \times 2240} = 4.1$ ton/"^{2}

Tie member to Arch.
(See Fig. 10).
Greatest horizontal thrust = 44,050 lbs.
Area of tie member $= (2 \times 16) \times \frac{1}{8} = 4''^2$

Stress in tie $= \dfrac{44{,}050}{4 \times 2240} = 4.92$ ton/"^{2}

Internal Columns.

To keep the size of the internal columns down to a minimum, these were made in square section as shown on Fig. 11.

Maximum vertical reaction =
2 x 41,970 = 85,940 lbs.

Concrete takes:—8 x 8 x 900	=	57,800 **lbs.**
Steel walls take 4 x ⅛ x 8 x 13,000	=	52,000
Steel bars take 4 x 0.785 x 13,000	=	40,700
		150,500 lbs.

Structural wall column.
(See Fig. 12).
Reaction = 41,970 lbs.:

Concrete takes 6 x 6 x 900	=	32,500 **lbs.**
2 ⅛" side plates take 2 x 9 x ⅛ x 13,000	=	29,300
		61,800 **lbs.**

Long walls:—Supports to dovetail units forming roof.
Span between columns = 6' (generally).
(See Fig. 13).
w = 760 lbs./'

$$M = \frac{760 \times 6^2}{8} = 3420 \text{ lb.-ft.}$$

$$z \text{ required} = \frac{3420 \times 12}{2240 \times 8} = 2.29''^3$$

Channel as Fig. 14.

$$I = \frac{\frac{1}{8} \times 10^3}{12} + 2 \times 2.875 \times \tfrac{1}{8} \times 5^2$$

$$= 10.4 + 17.9 = 28.3''^4$$

$$z = \frac{28.3}{5} = 5.66''^3$$

Span across centreline of arch.
(See Fig. 15).
w = 770 lbs./'
Self-weight = 20 lbs./'
W = 2240 lbs. (Crane).

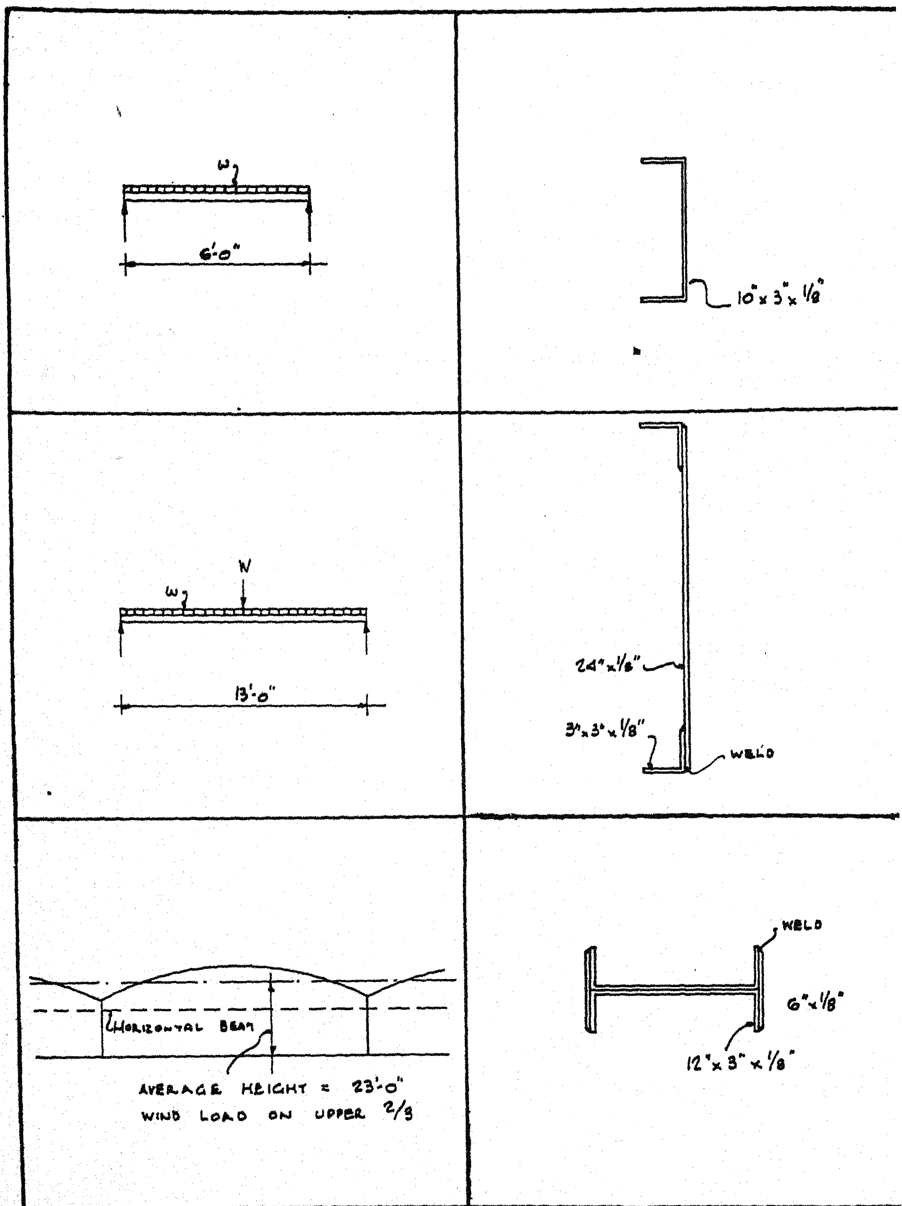


Fig. 13, (upper left)—wall beam at gable end. Fig. 14, (upper right)—section of wall beam, 6-foot span. Fig. 15, (center left)—wall beam at top of gable end. Fig. 16, (center right)—section of wall beam, 17-foot span. Fig. 17, (lower left)—wind load diagram, 360-foot walls. Fig. 18, (lower right)—section of horizontal wind beam, 360-foot walls.

$$M = \frac{770 \times 13^2}{8} + \frac{2240 \times 13}{4}$$

$$= 16{,}300 + 7{,}300 = 23{,}600 \text{ lb.-ft.}$$

$$z \text{ required} = \frac{23{,}600 \times 12}{2240 \times 8} = 15.8''^3$$

Section as shown on Fig. 16.

$$Ixx = \frac{\frac{1}{8} \times 24^3}{12} + \frac{2 \times \frac{1}{8} \times 3^3}{12} + 2 \times 3 \times \tfrac{1}{8} \times 10.5^2$$

$$+ 2 \times 3 \times \tfrac{1}{8} \times 12$$

$$= 144 + 0.56 + 82.5 + 108 = 335.06''^4$$

$$z = \frac{335.06}{12} = 27.9''^3$$

Long walls, resistance to wind.
Wind pressure = 15 lbs./ft.^{2}
(See Fig. 17).

$$\text{Average wind load per ft.} = \frac{(23}{4} + \frac{23)}{6} \times 15 = 144 \text{ lbs./ft.}$$

Resisted by horizontal beam spanning alternately
35′—4½″ and 24′—7½″.
Beam section shown on Fig. 18.

$$I = \frac{\frac{1}{4} \times 12^3}{12} + \frac{2 \times 6 \times \frac{1}{4}^3}{12} + 2 \times 6 \times \tfrac{1}{4} \times 6^2$$

$$= 36 + 0 + 108 = 144''^4$$

$$z = \frac{144}{6.25} = 23.0''^3$$

Maximum M due to wind =

$$\frac{144 \times 35.375^2}{10} = 18{,}000 \text{ lb.-ft.}$$

Maximum stress due to wind =

$$\frac{18{,}000 \times 12}{2240 \times 23} = 4.2 \text{ ton}/''^2$$

Beam also carries weight of wall over. 11′ high.
Load:—dovetail sheets = 2 x 4 = 8 lb./ft.^{2}
Ash fill = 25
Plaster = 10

43 lb./ft.^{2}

M due to wall = (See Fig. 19.)

$$\frac{11 \times 43 \times 6.5^2}{10} = 2{,}000 \text{ lb.-ft.}$$

I of weak axis of beam =

$$\frac{12 \times \frac{1}{4}^3}{12} + \frac{2 \times \frac{1}{4} \times 6^3}{12} = 9.0''^4$$

$$z = \frac{9.0}{3.0} = 3.0''^3$$

Maximum stress due to wall load =

$$\frac{2{,}000 \times 12}{2240 \times 3} = 3.56 \text{ ton}/''^2$$

Greatest combined stress = 4.2 + 3.56 = 7.76 ton/2[2]

Resistance of 240′ walls to wind.
(See Fig. 20).
Total wind load per ft. = 2/3 x 26 x 15 = 260 lb./ft.
Beam carries:—

$$\left(\frac{14}{2} + 3.3 \times \frac{10.35}{12}\right) \times 15 = 148 \text{ lbs./ft.}$$

$$\text{B.M. due to wind} = \frac{148 \times 30^2}{8} = 16{,}700 \text{ lb.-ft.}$$

$$z \text{ required} = \frac{16{,}700 \times 12}{2240 \times 8} = 11.2''^3$$

Section of beam shown on Fig. 21.

$$I = \frac{\frac{1}{4} \times 12^3}{12} + 2 \times 6 \times \tfrac{1}{8} \times 6^2 = 90''^4$$

$$z = \frac{90}{6} = 15''^3$$

"E" Type columns.
These are stiff columns in the walls to carry the reactions of the horizontal wind beams. (Fig. 22.)
Direct load = 6 x 770 + 11 x 43 x 6 = 7,440 lbs.
Wind load = 30 x 144 = W = 4,800
(See Fig. 23).

$$\text{M due to wind} = \frac{4800 \times 23}{.4} = 27{,}600 \text{ lb.-ft.}$$

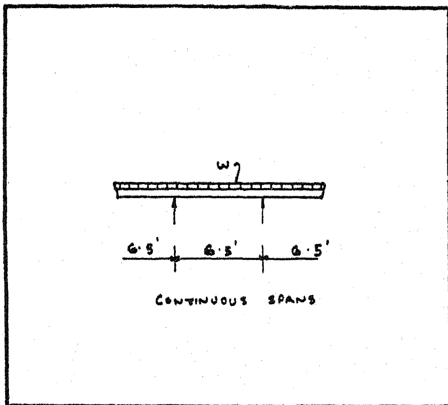
Column section shown on Fig. 24.

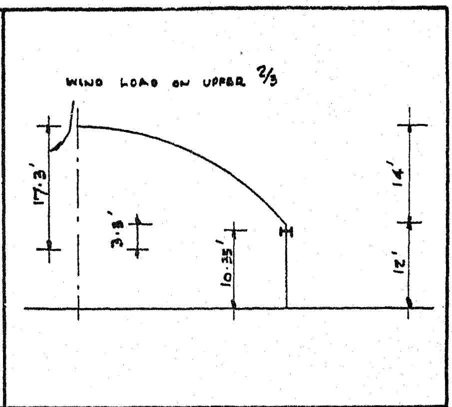
$$A = (18 + 18 + 14 + 14 + 12) \times \tfrac{1}{8} = 9.5''^2$$

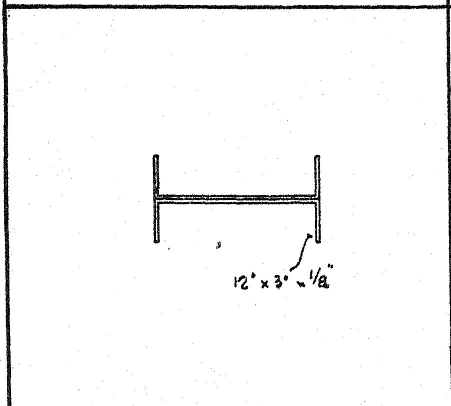
$$I_{yy} = \frac{\frac{1}{4} \times 6^3 \times 3}{12} = 13.5''^4$$

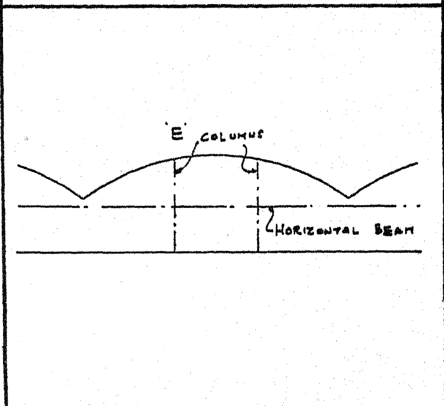
$$z_{yy} = \frac{13.5}{3} = 4.5''^3$$

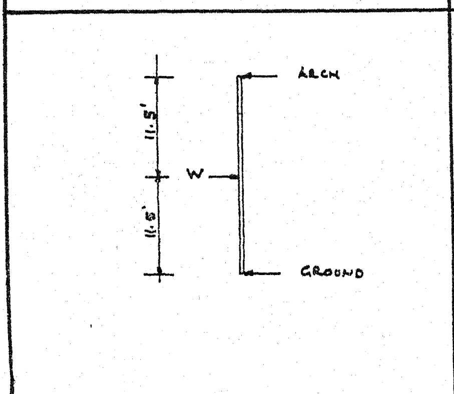
$$g_{yy} = \sqrt{\frac{13.5}{9.5}} = 1.19''$$











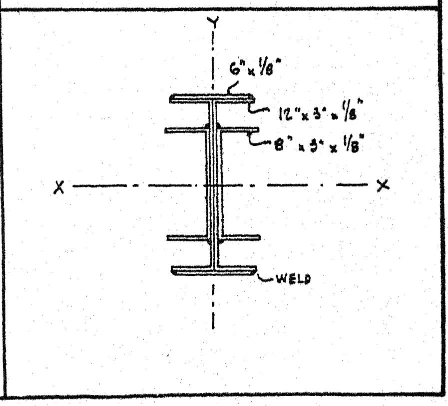


Fig. 19, (upper left)—wall load on horizontal wind beam, 360-foot walls. Fig. 20, (upper right)—wind load diagram, 240-foot walls. Fig. 21, (center left)—section of horizontal wind beam, 240-foot walls. Fig. 22, (center right)—wind load diagram for "E" columns. Fig. 23, (lower left)—application of wind load on "E" columns. Fig. 24, (lower right)—section of "E" columns.

$$\frac{1}{g} = \frac{12.5 \times 12}{1.19} = 126$$

Allowable stress $= 2.72$ ton/"^{2}

$$\text{Direct stress} = \frac{7740}{2240 \times 9.5} = 0.35 \text{ ton/"}^2$$

$$F = 0.35 + 7.5\ \frac{(1 - 0.35)}{2.75}\ (1 - 0.002 \times 126)$$

$$= 0.35 + 7.5 \times 0.811 \times 0.748 = 5.23 \text{ ton/"}^2$$

(Increased allowable stress under L.C.C. regulations.)

$$I_{xx} = \frac{\frac{1}{4} \times 12^3}{12} + \frac{\frac{1}{4} \times 8^3}{12} + 2 \times \tfrac{1}{8} \times 6 \times 4^2 + 4 \times \tfrac{1}{8} \times 6 \times 6^2$$

$$= 36 + 11 + 24 + 108$$

$$= 179"^4$$

$$z_{xx} = \frac{179}{6} = 29.8"^3$$

$$g_{xx} = \sqrt{\frac{179}{9.5}} = 4.34"$$

$$\frac{1}{g} = \frac{23 \times 12}{4.34} = 66.5$$

Allowable stress $= 5.58$ ton/"^{2}

$$\text{Bending stress} = \frac{27{,}600 \times 12}{2240 \times 29.8} = 4.96 \text{ ton/"}^2$$

Maximum combined stress =
$4.96 + 0.35 = 5.31$ ton/"^{2}

Having, thus, decided the sections of the main members, the principal arch drawing was prepared. From this drawing, shop details were drawn out later.

The foregoing data illustrates one of the great advantages of this method of light-plate construction. It will be noted that the main arch members carry loads which stress them in the region of the maximum allowable figure, so that the unavoidable amount of material over the theoretical minimum is kept as low as possible. This may be contrasted with roofs made of rolled steel sections, where, a design having been taken out, it is often only possible to use a section much heavier than that required, owing to the limitations of the sections rolled.

An idea of the lightness of the construction will be obtained from Fig. 25, which is an isometric view of the apex of the arch, and from Fig. 2, an isometric of a typical arch heel, showing also the general construction of the roofing.

Fabrication.—By using steel and concrete combined, the internal columns were kept down in size without the use of a heavy steel section. The ⅛" walls were considered as hoop reinforcement to the concrete, so increasing the allowable concrete stress. The reinforcing bars were tack welded to the 8" by 8" angles, which were then welded together continuously at their edges.

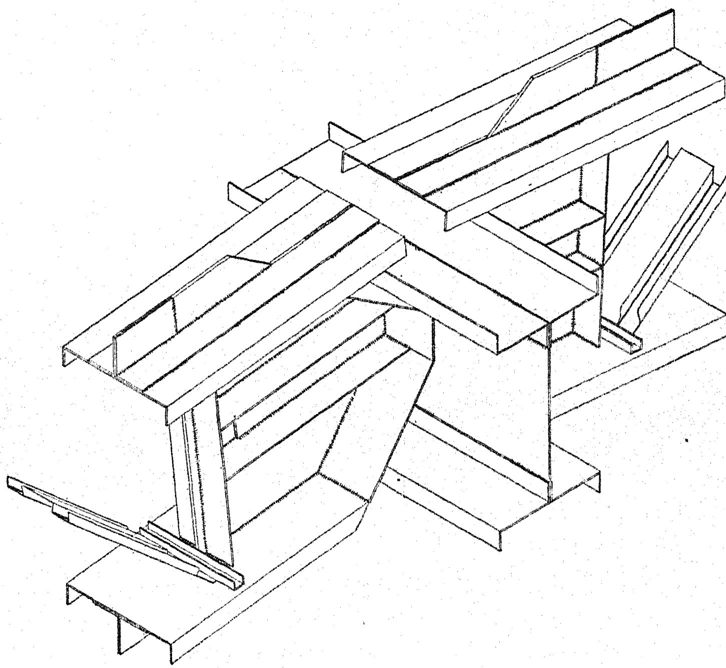


Fig. 25. Isometric view of top articulation and centre longitudinal beam.

The structural wall columns were made in a similar manner. The intermediate wall columns, which carry no design load, were fabricated from 16-gauge sheet, the component parts being arc welded together to form the required sections.

The stiff wall columns were built up of flats, angles and channels of 1/8″ plate. These simple sections are easily folded to a high degree of accuracy, so that the fit-up for welding was good, and only the simplest type of jig was required.

The separate parts for the arch ribs were also of simple shapes. The first segment made was in the nature of an experiment. Careful note was taken of the length of each part and its position before welding. After welding up, the dimensions were checked. Production jigs were then made accordingly, and the repetition parts were after that turned out with no difficulty. Each half-arch was made in 3 pieces of about 12′ length, which were welded together before erecting, so that only erection bolts were required at the heels and apexes.

A further advantage of the method of construction becomes apparent when it is realized that each half-arch, ready for erection weighed only 0.9 ton, so that the only lifting tackle required was a 30-foot pole, a set of pulley blocks and a hand winch. Fig. 26 shows a half-arch being fixed in position.

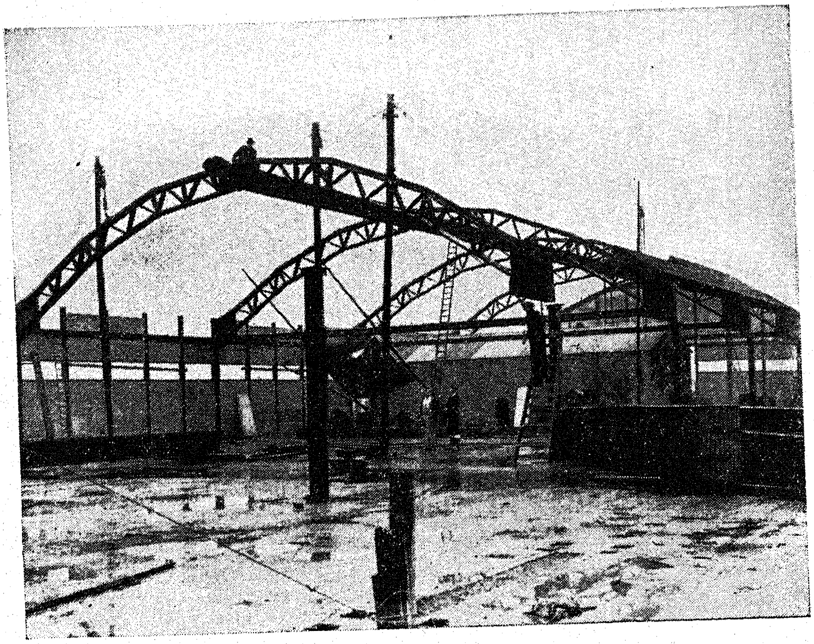


Fig. 26. Half arch being fixed in position.

In order to carry the glass, light glazing bars were put in at 2′ centres, and these bars were carried on purlins. These purlins were of economical section owing to the large depth available, which permitted the use of flanges only ⅛″ thick. The purlins were made up in 30′ lengths so that they could be erected across the arches with erection bolts only. The plate for the purlin sections was obtainable in lengths up to 12′, and the necessary lengths of plate were made up by butt-welding sheets together.

The ties were of simple form. Here again, sheets were butt-welded to make the runs of about 50′ required. Hangers were placed at the centres of the arches to pick up the ties so as to eliminate sag over the comparatively long span.

The wind beams in the walls to take the wind load consisted of built-up H-sections, with the cross-pieces placed horizontally, so as to be most effective in that plane. The sections are shown on Figs. 18 and 21. The pieces were made up in the shop in about 30′ lengths, and site welds were made after erection, as the beams are continuous along all four walls.

Erection.—The site and foundations being prepared, the internal columns were lifted and set in position with holding-down bolts. The steel columns were so light that 2 men lifted them with no difficulty without tackle. After lining and plumbing, the columns were filled with concrete and vibrated, the cap plates then being welded on.

The structural wall columns were erected in a similar manner, and at the same time the intermediate, non-structural wall columns were fixed in position.

Erection of the arched roof members was commenced in the first bay from a gable end. This arch was temporarily strutted in place until the next arch in line was up, the arches then being braced together by means of the top purlin. The ties were put in as soon as the heels of the arches were bolted to the column caps, so that the structure was self-supporting from then on, no further strutting being required.

The roof units were being prepared meanwhile, and were erected by separate gangs as soon as the arches were in position. The units were drilled to correspond with holes in the arch chord flanges, so that positioning was automatic. The holes were 3/8″ diameter at 2′ centres, so that they did not detract to any extent from the strength of the arch ribs.

As soon as sufficient of the roof units were in place, the work of fabrication was transferred to the factory floor, which gave almost perfect conditions for setting-out, welding and other shop operations, the floor being fairly levelled-off concrete.

Erection being so simple, the rate of manufacture of the structural members was the limiting factor to progress, and by increasing the number of platers and welders, a remarkably fast erection program was maintained.

Fig. 27. General view of finished factory bay.

Fig. 27 is a view of the last bay to be erected, taken after most of the structural work was completed. The expanse of uninterrupted floor will be noted, and also the large amount of roof lighting.

After the undersides of the roof units had been painted with a light-reflecting paint, the natural light inside the factory during daylight hours was excellent in both quality and quantity.

Construction.—Mild steel plate was used throughout for the structural members. At the commencement of the job, some difficulty was experienced in obtaining supplies of the raw material, owing partly to its newness as a structural medium, but chiefly to the general shortness of steel at the time. Since then however, mild steel plate has become increasingly popular. As an example may be stated the fact that Messrs. Richard-Thomas are erecting in South Wales extensive mills intended for the manufacture and supply of sheet strip.

No electrical supply being available at the beginning of the job, it was decided to fabricate using petrol sets at the site, as the cost of freightage more than outbalanced the extra cost of current. At the peak of the work, 6 petrol sets were in constant daily use. Later, A.C. plants replaced the petrol sets.

As nearly all the welding was downhand shop work, the best setting for the machines was soon discovered, and the operators quickly became proficient at turning out first-class welds at a good rate.

The welding was carried out with shielded arc electrodes and consisted of single runs with $5/32''$ rods, to give $1/8''$ fillets. The total length of welding in the job was 46,620 feet. This figure experience has shown to be about 8% more than was really required; as it was found possible towards the latter part of the fabrication to cut down the amount of welding in those cases where the welding required was purely nominal. For example, on long lengths of plate connections, and especially on stiffeners, spaced welds of 1″ or 2″ length were found to be all that were necessary.

Costs.—As the existing factory which was the property of the owners of the new building was equipped for folding and cutting steel sheets, it was decided that the most economical way to carry out the work was for the owners to purchase the sheet, and prepare and deliver it to the site, ready for the welding fabrication.

The contractor agreed to do all the welding, both shop and field for the flat rate of 9 pence per foot run of weld. This figure covered everything necessary for the execution of the work, including power, jigs and rods, and also the setting up of the parts for welding. The total cost of the welding only was thus £1,748. The cost of the steel sheets, delivered to the company's existing works averaged £13 per ton.

A careful check was kept on the cost of folding, cutting and delivering the sheets to the new site, and this worked out at nearly £5 per ton. (Note. These figures include a normal allowance for contractors' profits, so that they form a basis of comparison.) The weights of steel in the various parts of the structure, together with welding footages and costs are tabulated as follows:

	Weight of Steel	Feet of Welding	Cost of Steel	Cost of Welding
Arches	77 tons	18,600	£1,386	£ 697
Purlins	52	15,000	936	562
Structural Columns	14	6,840	252	256
Wind Beams	7	2,800	126	105
Ties, hangers, etc.	4	2,220	72	83
Intermediate Columns	6	1,160	108	44
Totals	160 tons	46,620	£2,880	£1,748

Cost of structure (Excluding erection) £4,628

The cost of erection has not been taken into account as, when making comparisons, there would not be a great deal of difference in cost between the new design and the old. A much greater saving in cost would be found with roofs of larger span and at greater heights above ground level, as the lesser weight of the new sections would mean correspondingly lighter tackle, and ease of handling.

Proportionate Saving on Previous Methods.—For purposes of comparison the writer made provisional designs and took out quantities for roofs of the same area constructed by normal methods. Two such designs were calculated:

a). For a roofing system similar to that used in the factory described, that is, roof units, screed, etc.

b.) For a lighter and cheaper roof of corrugated asbestos or other material of low weight.

The data obtained is tabulated below:

	Normal Design		New Design
	(a)	(b)	
Weight of Steel	220 tons	190 tons	160 tons
Cost of Steel and Fabrication (At £34 per ton)	£7,480	£6,460	£4,628
Percent Saving, new design over normal	38.3%	28.4%	

The price stated for fabricated riveted steel was in force at the time the work was undertaken, and may be subject to the following remarks:

Steel prices were above the average for the past few years, due to the general shortage of structural steel at the time. As against this,

it is to be expected that when prices return to normal, the cost of steel sheet will be proportionately lower owing to its increased popularity and ease of obtainment.

Taking the normal price of ordinary riveted steelwork, in purlins, trusses, columns, etc., fabricated and delivered on site as £28 per ton, it will still be possible to show savings of about 20% over an equivalent "heavy" roof design and about 12% for the "light" roof. Labour costs have not been considered separately here, as these would be approximately the same for riveted or welded construction.

Of course, there can be no real comparison between heavy and light roofs, the former possessing qualities which greatly outweigh any considerations of first cost. The number of buildings erected annually which have roofs of large area must run into thousands. The general adoption of a construction based on the example described here would result in the saving of large sums, which could be devoted to improvements in the buildings themselves, or in many other ways to the advantage of industry as a whole.

Nor is such a result difficult of attainment. The materials are easy to get and will in the future be easier. Welding sets are mobile, and can be taken as far as fuel supplies can reach them. Where electric power is available so much the better, and welding operators, welding supplies and rods can be obtained in all parts of the civilized world, and beyond these things, no special and expensive plant or apparatus is required.

Conclusions.—It will be realized that the design described in this paper is only one of many to which the new method of construction can be adapted.

An extension of the principle of the design which is the subject of this paper would be one which would eliminate the necessity of tie-bars, this being achieved by making the arches 2-hinged instead of 3. This means that the heels of the arches would be rigidly fixed to the supporting columns which would be designed to take bending stresses. Thus, an uninterrupted headroom could be obtained over the whole area of the building, which is in many cases an essential condition of the design. Other standard methods of spanning roofs are also very suitably carried out with thin-plate construction.

For example, N-trusses, Warren girders, French and other pitched trusses, can easily be fabricated. For larger spans, thicker plate, say ¼", could be used as a basis for the heavier members, this plate being reduced to ⅛" when the stresses were sufficiently reduced.

In the arches described, the diagonal members were made of 16-gauge sheet for economy of material. The ends of the diagonals were bolted to the chords, as 16-gauge sheet is not easily welded. For larger trusses, the diagonals would need to be of thicker section and consequently could be arc welded in position.

The advantages of thin-plate construction are summed up below:

A. Saving in First Cost.—As has been shown, there is a definite saving in initial cost over more usual methods of construction. This

is due firstly to the saving in material, which is made up of several items:

1. "Flexibility" of sections, by which is meant the ability to use sections which approximate closely the theoretical minimum.
2. On tension flanges, there are no reductions for rivet and bolt holes.
3. On compression chords and flanges, greater width can be given to the members without a large increase in weight, thus making it possible to use stresses nearer the maximum allowable.
4. On compression members generally, the metal in the section can be arranged so that the ratio $\frac{\text{effective length}}{\text{least radius of gyration}}$ is relatively low, so that decreased working stresses have to be considered much less often.
5. The amount of scrap material will be less than is found with rolled sections.

Other savings in first cost come from the ability to fabricate easily at the site, thus saving the transport of large and heavy members. Riveting, apart from the necessary field riveting, is usually only carried out in the shop, where heavy plant is installed for the purpose.

The saving in weight of the upper structure is carried down through the columns, so tending to reduce these in size, and also the foundations.

Time and labour costs, both in fabrication and erection are reduced owing to the comparative lightness of the separate parts.

With regard to service life, with the present perfection of welding materials, and the growing improvement in the standard of welding methods, testing and control, buildings now being erected of arc welded steel are certain to have a life at least equal to riveted structures. Bearing in mind that there are no rivets to corrode, and no rivet holes to wear oval, the life of a welded building will probably be even longer than its riveted counterpart.

The thinness of the plate should not adversely affect the service life. All mild steel needs to be painted after erection, and if this is carried out with normal care, the plate will not tend to rust any more than rolled steel.

On the score of upkeep, a welded frame of the type here described has an inherent elasticity which will allow it to take up the strains due to inequalities of loading, wind and temperature with less cumulative harmful effect than to a riveted frame.

The effects of corrosion will also be less marked, as there are no parts such as rivets which need more or less frequent replacement.

A further advantage of the system lies in its adaptability to building materials and methods. In the example given here, the structure was designed to fit in with unusual types of walls and roof. With a little ingenuity on the part of the designer, it could be adapted for use with more common materials such as brickwork, timber, asbestos sheet, etc.

If, as is wise, part of the saving in cost of the structural steelwork is devoted to the employment of better quality wall and roof materials, a further saving, that of heating the building, will be noted over a period.

Let it be hoped that wall and roof materials will get this attention that they merit, as this leads to improved hygienic conditions inside such buildings as factories, hangars, halls, etc., which in turn gives rise to contented workpeople and increased output. Finally, the writer would like to repeat an earlier statement, that such ends can be attained only by the adoption of electric arc welding as the one method of building up the composite structure.

Chapter V—Arc Welded Steel in Theatre Construction With Special Reference to Balcony Construction

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Preface.—In the preparation of this article, it has been the author's intention to show a true comparison of welded versus riveted steel, and in this endeavor he has taken every means to make the designs as economical as possible for both methods of construction, to satisfy the same design conditions.

The problem herein treated is an actual theatre design on which bids were taken and which is now* under contract and construction. Some modifications in the design were made before the contract was finally awarded but none which changed the general character of the work. The original design is shown herein.

The data as given for weights, shop operations, etc., and comparisons of the same are mathematical determinants. The costs and cost comparisons based on the former may be subject to some variation, due to locality, local labor and local conditions.

Material prices used in the tables herein are based on material costs, including freight, at this locality, and this accounts for the uniformity of unit price for the various classes of material, the freight rate from different shipping points balancing the differential in mill price.

Labor prices for riveted construction are usual estimating costs for the moderate size shop in this locality. Labor prices for welded construction are based on data published in "Procedure Handbook of Arc Welding Design and Practice." These cost figures were arrived at by using the time of welding as above mentioned with the local rate of high class welders. The unit costs and, therefore, the ultimate costs, will naturally vary somewhat for different localities and different local conditions. Those used are believed to be correct for this locality and to show a true comparison of relative costs.

Introduction.—In theatre operation the "seat" is the unit of measure. The number of available seats in a house is a large factor in its economic set-up, and the cost per seat is therefore a vital factor as affecting capital charges against each unit of production.

Theatre design is highly specialized in its nature. The designer must carefully consider three major elements: (1) Public Safety; (2) Operation Characteristics; and (3) Construction Cost. These factors are very closely interwoven and must be carefully correlated, but for purposes of analysis they may be differentiated.

In this article public safety only will be considered as regards structural stability; and this, together with the third element, construction cost, will constitute the phase to be emphasized.

To create maximum numbers of available seats, at lowest possible

*At time of writing paper.

cost per seat, balconies are resorted to in many cases. The design of structural framing for such balconies presents peculiar and varied problems and offers large opportunity for ingenuity as to choice and use of materials and methods of fabrication and erection.

The purpose of this article is to show the logical application of arc welded structural steel to framing in theatre construction, with particular reference to balcony construction, and a comparison of an arc welded design with a riveted design for the same conditions.

Specifically, this article will be restricted to the framing for the portion of balcony shown in Sketch A, Fig. 1, with complete analysis and design of girders G-1, G-2 and G-3, as indicated in plan Sketch B, and in sectional elevation in Sketch C, Fig. 1.

Statement of Problem.—The problem, herewith presented, consists of the framing for a portion of a concrete theatre balcony, extending approximately 32 feet from line of columns C-1 to front edge of cantilever portion of balcony. (See Sketch A, Fig. 1.)

The width for the front 14 feet is 51′-9″ and 49′-9″ for the remainder; all clear of supporting columns.

Sketch C, Fig. 1, shows typical cross section through the balcony, and Sketch D, a cross section through the concrete stair leading to the balcony.

The supporting frame consists of two cantilever girders G-1, two reaction girders G-2, and one main support girder G-3, into which G-1 and G-2 frame in such manner that G-1 cantilevers 15′-0″ beyond G-3. Girder G-3 has a clear span of 49′-9″. (See Sketch B, Fig. 1.)

The design and comparison in riveted and welded construction of Girders G-1, G-2 and G-3 form the subject of this article.

Design Specifications.—The designs are prepared on conformity with recommendations contained in specifications of American Institute of Steel Construction, American Society for Testing Materials, American Welding Society, and "Procedure Handbook of Arc Welding Design and Practice", as to materials, workmanship, unit stress values, design formulas, etc.

Design Curves.—As a basis for design of the girders, external shears and bending moments were computed.

The loads used in these computations are those usually encountered in construction of this type. Live loads used were 90 lbs. per sq. ft. for cross over and stair, and 75 lbs. per sq. ft. for remainder; impact was taken at 50% of live load; and the actual dead load computed.

Design of Girders G-1 and G-2 Riveted Construction.—The method of design chosen for these girders is the flange area method, treating the flanges as resisting all of the moment and the web as resisting all of the shear, and no part of the moment being resisted by the web plate.

The reasons for selecting this method for these girders are:

(a) Due to the necessity of cutting the tops of the web plates of G-1 and G-2, in order to frame to G-3, and the necessity for providing full moment resistance in the top flange at this point on that account, it would be irrational and impracticable to use either a moment of

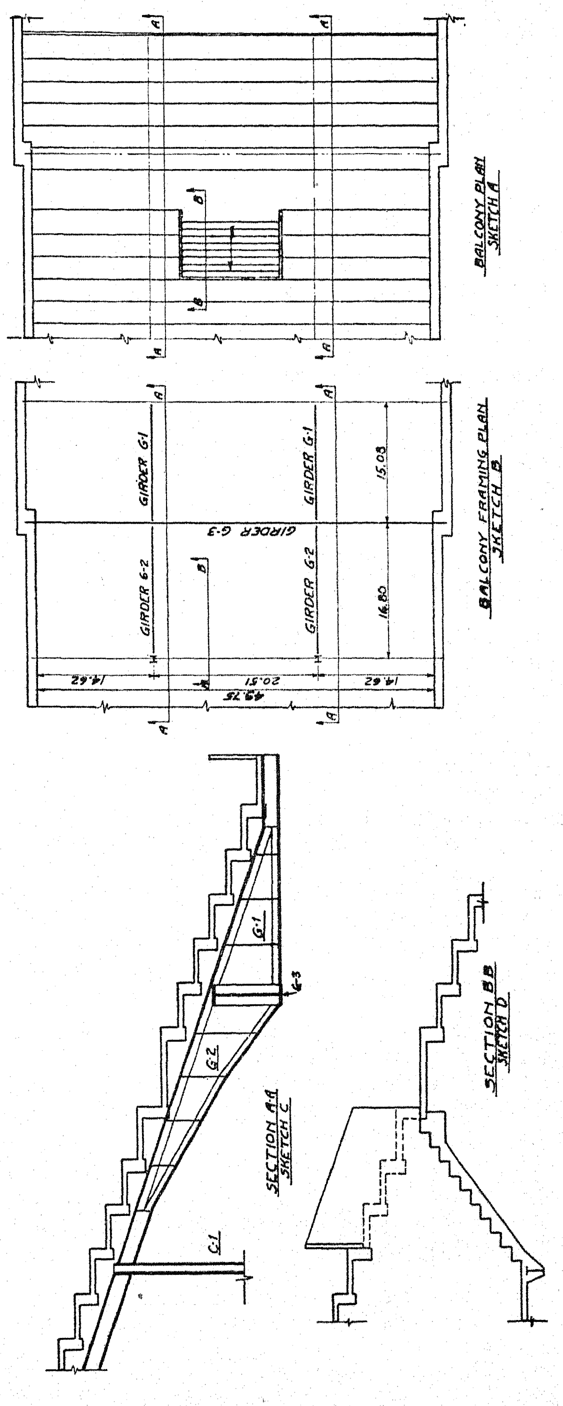


Fig. 1. Framing for theatre balcony.

inertia method of design, or a composite design wherein a portion of the moment is considered as being carried by the web plate.

(b) An attempt to design a connection of web plates of G-1 and G-2 to G-3 in such manner that it would be capable of resisting a substantial portion of the moment would be cumbersome and irrational.

(c) To require the webs of G-1 and G-2 to resist bending moment would, of necessity, put tension on the rivet heads of the main connecting stiffeners, which is undesirable and is to be avoided.

(d) A splice of the web plate into the connection to G-3, where external moment is a maximum, would be difficult and expensive, due to rivet stress in such splice due to such moment.

Having determined the logical method of design, a trial section is chosen.

Stiffeners are considered necessary at points of load concentrations, irrespective of unit shear values.

Design of Girder G-3 Riveted Construction.—The moment and shear curves are based on 125.5 Kips concentrated load where G-1 and G-2 frame to G-3, and a uniform dead load of approximately 300 lbs. per linear foot, making total reaction at end of girder 133.0 Kips.

The method which is used in this design is the moment of inertia method, data for both net flange area and gross flange area being computed.

It is presumed that the fabricator will require one or more web splices, and since the moment of inertia method of design is used, the splice must be designed to take all the shear and its proportionate part of the moment.

Design of Connection of G-1 and G-2 to G-3, Riveted Construction.—For the purpose of making one such connection the weight of necessary material is 665 pounds. 86 field rivets must be driven for each splice and 68 shop rivets are necessitated by each splice.

Fabrication of Riveted Construction.—The principal operations involved are: flame cutting, shearing, punching, grinding, shop assembly and bolting up, and riveting. To these must be added shop drawings, shop billing and laying out; altogether nine (9) kinds of operations, besides painting.

The equipment involves major fabricating machinery such as plate and angle shears, punches, drills, bulldozers, air compressors; minor equipment such as pneumatic riveting hammers, oxy-acetylene flame cutting torches; and motors for supplying power to shear, punches, drills, bulldozers, and air compressors.

Such machinery represents extensive capital investment in such equipment as well as in building area for housing such equipment.

Erection requires an air compressor and pneumatic riveting hammers, in addition to necessary hoists.

Design of Welded Construction.—The design of Girders G-1, G-2 and G-3 of welded construction, with connections and details is shown in Figs. 2, 3 and 4.

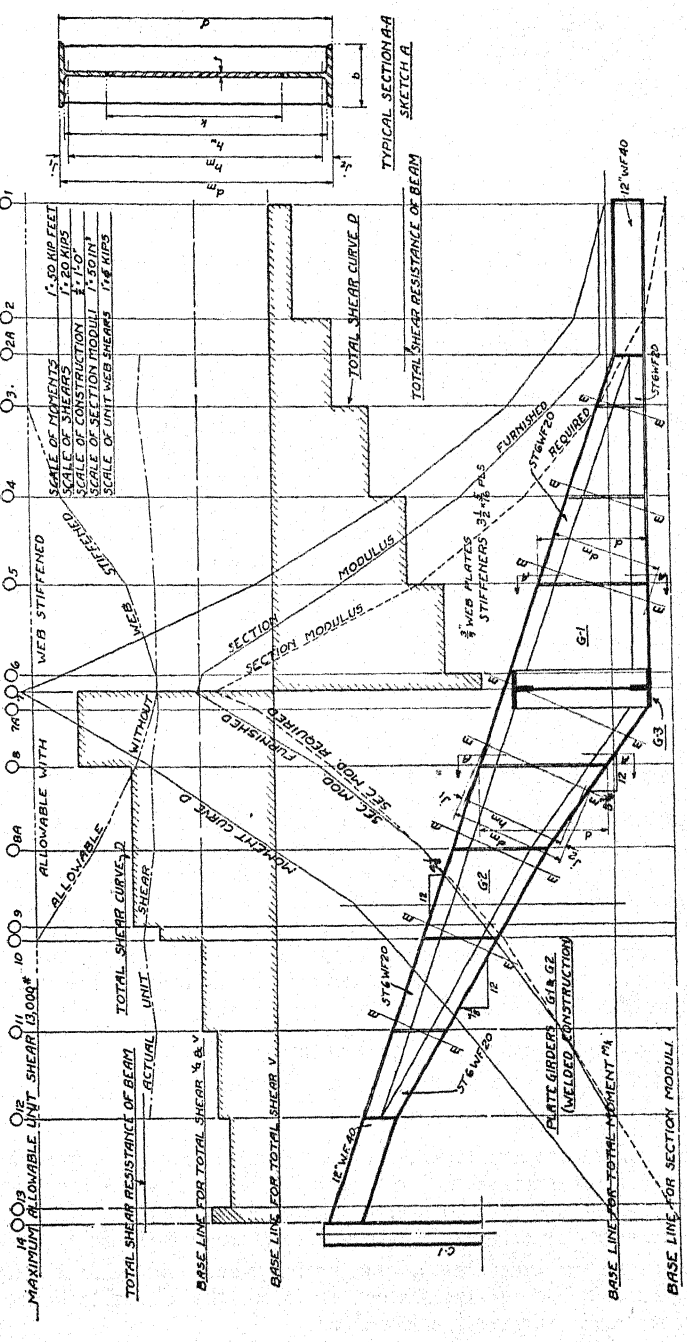


Fig. 2. Design of girders for welded construction.

Design of Girders G-1 and G-2, Welded Construction.—The design, (See Fig. 2), is based on the same moment and shear curves as used for design of the girders for riveted construction, which are superimposed on Fig. 2.

The method used in the design of these girders in welded construction is the Moment of Inertia method since all may be made a homogeneous mass, no deductions are necessary for rivet holes, and the same limitations as to connections of G-1 and G-2 to G-3 do not exist as they did in the case of riveted construction.

Stiffeners are used in the same locations and for the same reasons as for riveted design.

The trial design selected consists of a 12″ wide flange beam section which is split and spread and a web plate interposed as shown on the drawing Fig. 2.

A typical section is shown in Sketch A, Fig. 2 (vertical plane). In this section, d is the depth back to back of flanges, d_m the minimum depth where this differs from the vertical depth, h_w the web plate height to inside of flange legs, and k the distance between toes of flange stems. K_m is used in design to represent the k value corresponding to d_m.

Fig. 2 shows external moment curve "D", total external shear curve "D", total shear resistance of beam portions, actual and allowable unit web shears, section moduli required, section moduli furnished, and the general type of design with material of design.

Typical details and types of welds are shown in Fig. 4.

Design of Girder G-3 Welded Construction.—The external moment and shear curves are the same as for riveted design.

The girder is shown in elevation in Sketch A, Fig. 3 only the left end and center portion being shown; the right end is symmetrical to the left end.

Sketches B, C and D, Fig. 3, show dimensions for G-1 and G-2.

The web is designed to take all the shear and, in this design, it consists of all material except the horizontal portions of the flanges; that is, it is composed of the web plate height, plus the stems of the flanges.

Relatively low allowable unit stress value is used where the flange splice occurs. The method of building up this section so as to obtain a satisfactory section and still not exceed the allowable fibre stress is shown in Sketches B and I in Fig. 4.

The web splice must be designed to resist:

(a) Its share of the bending moment stresses

(b) Its share of the shear stress

The bending moment stresses in the web are horizontal forces, either tension or compression according as they are below or above the neutral axis. The amount of this horizontal force is shown in Sketch C, Fig. 4, where the intensity of stress in web due to moment is shown.

The maximum unit stress in the portion where web plate is spliced is 14.0 Kips per square inch which is within the allowable limit for tension or compression with shielded arc.

The vertical shear to be resisted is negligible.

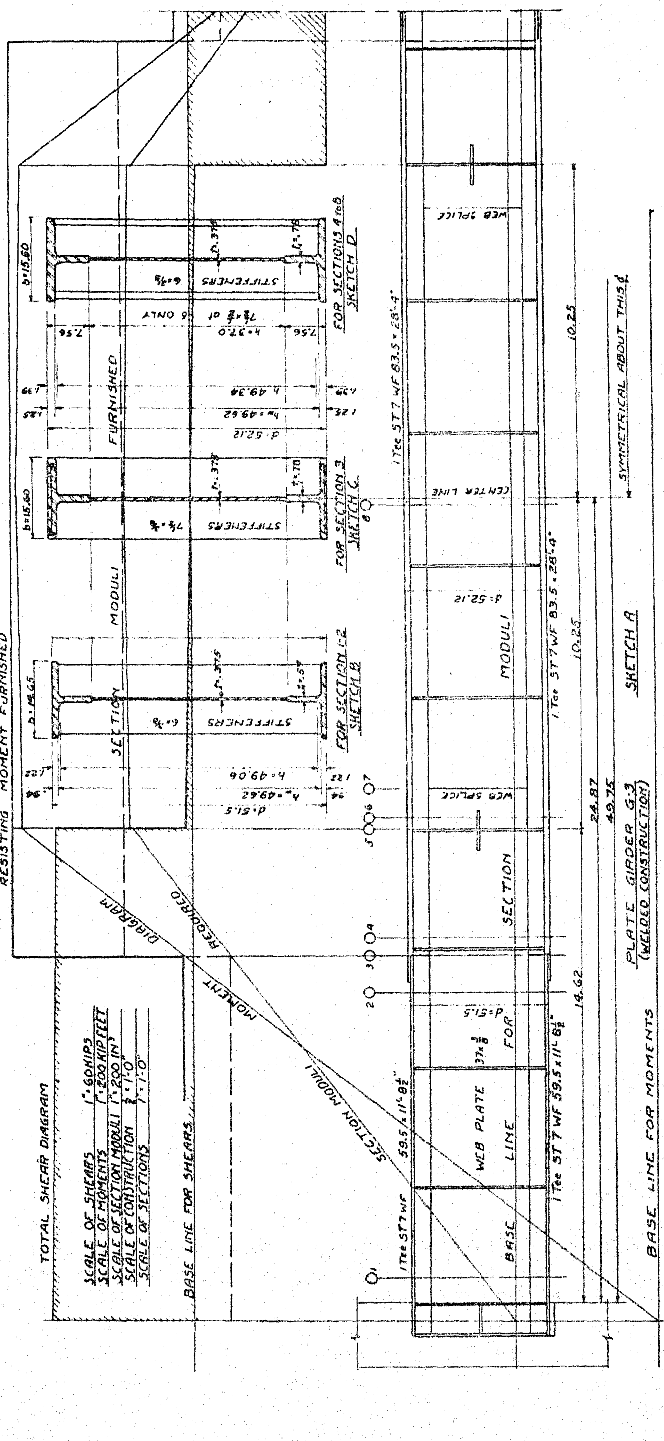


Fig. 3. Left end and center portion of welded girder.

Connection of G-1 and G-2 to G-3, Welded Construction.—Attention is directed to the homogeneous character of all the parts forming this connection. (See Fig. 4.) The total weight of detail material, which includes erection hitches and stiffeners s_a and s_b which are shop welded to G-3, as well as all weld material for all shop and field welds, is 161.4 lbs., which is only 24.2% of the weight required to make the corresponding connection in riveted construction.

It will also be noted that no holes are necessary in any of the main material, thereby avoiding loss of effective section, and expensive shop work. All holes to provide field erection and setting for field welding are in small detail members.

Fabrication of Welded Construction.—The design of welded connections is important, and in such design, the designer must constantly keep in mind fabrication and erection procedures, and so design the joints as to secure the necessary strength with the minimum of distortion or initial stress, and with due regard to the direction and kind of initial stress induced by fabrication and erection welding as compared with direction and kind of stress in the final structure.

For this reason a schedule of the "order of welding," both for shop fabrication and for field welding, should be carefully studied and prepared and rigidly followed.

The fabrication and erection of the welded construction is indicated in Figs. 2, 3 and 4. The operations involved are: flame cutting and arc welding; to which must be added shop drawings and shop billing; altogether four (4).

The equipment necessary involves oxy-acetylene flame cutting torches, and an arc welding machine for supplying the proper amperage and voltage for arc welding, with incidental welding tools.

A very small building is required to house the equipment, or it may be mounted on a truck and transported from place to place, thus materially lessening capital charges as compared with equipment required for riveted work.

Erection requires the same type of equipment, as for shop work. Provision is made for bolting the Girders G-1 and G-2 in position for field welding. No value is taken for these bolts except for erection purposes.

Only the welds marked (Field) on Sketch A, Fig. 4, are required in the field. All others are shop welds. The sizes, types, locations, and kinds of welds are indicated in Fig. 4. It is not intended that this drawing show all details of joints and welds, but sufficient to show the design and character and general scheme.

It is important that the designer select the type of joint, considering (1) the load and characteristics, (2) manner of application, and (3) cost of joint preparation and welding. The joint which meets the requirements as to strength, and costs the least is the one to be selected.

The location of work when welds are made should be predetermined so it is known if the welds will be flat, vertical, horizontal, or overhead, and if shop or field. The kind of weld as to whether butt, fillet, lap, edge, or plug should be determined and whether butt welds shall be plain, V, U, etc., and whether double or single.

After proper determination the same should be shown on the shop drawings so no design of joints is required in the shop or field.

Initial stresses due to welding should be considered in relation to ultimate design stresses. In Sketch A, Fig. 4, the field welding of this joint should be made in the following order and sequence:

First, erect G-2 and temporarily bolt. Start the butt weld between G-2 web and s_a at the top because, as this cools and contracts, the entire girders will move toward each other and no initial stress result; therefore full tension value may be realized. Proceed downward until the bottom is reached; then make the crossweld of bottom flange of G-2 to G-3; as this cools and contracts, initial tensile stresses result, but this is not objectionable since the external stress is compressive, (opposite in direction). It does not matter that some initial tension is in the lower part of the vertical butt weld as this lower portion is also in compression, and the entire length of this weld in shear which is not affected by tension or compression stresses on it. Next make the fillet welds on top of G-3.

Erect G-1 and proceed first with the cross flange weld at top; proceed with the vertical butt weld from top to bottom, and last the cross flange weld at the bottom. The reasons are the same as given for G-2.

Weight and Cost.—Comparative data is given in the accompanying tables.

COMPARISON OF WEIGHTS

	G-1 and G-2	G-3	Field Connection	Total
Welded Construction	4264	11148	323	15735
Riveted Construction	6330	13395	1330	21055
Actual Difference	2066	2247	1007	5320
Percent Difference	48.5%	20.2%	311.8%	33.7%

Above table shows comparative actual weights. It will be seen by reference to this table that Girders G-1 and G-2, riveted construction, weigh 48.5% more than the same girders, welded construction; Girders G-3, riveted construction, weighs 20.2% more than the same girder, welded construction; while the field connections, riveted construction, weigh 311.8% more than the same connections, welded construction. For the total work, the set of two (2) G-1 and G-2, with one (1) G-3, including field connections in riveted construction, weighs 33.7% more than the same girders, welded construction.

The difference in cost is not directly proportional to differences in weights due to variations in material price and volume of detail and shop work for riveted work as compared with welded work.

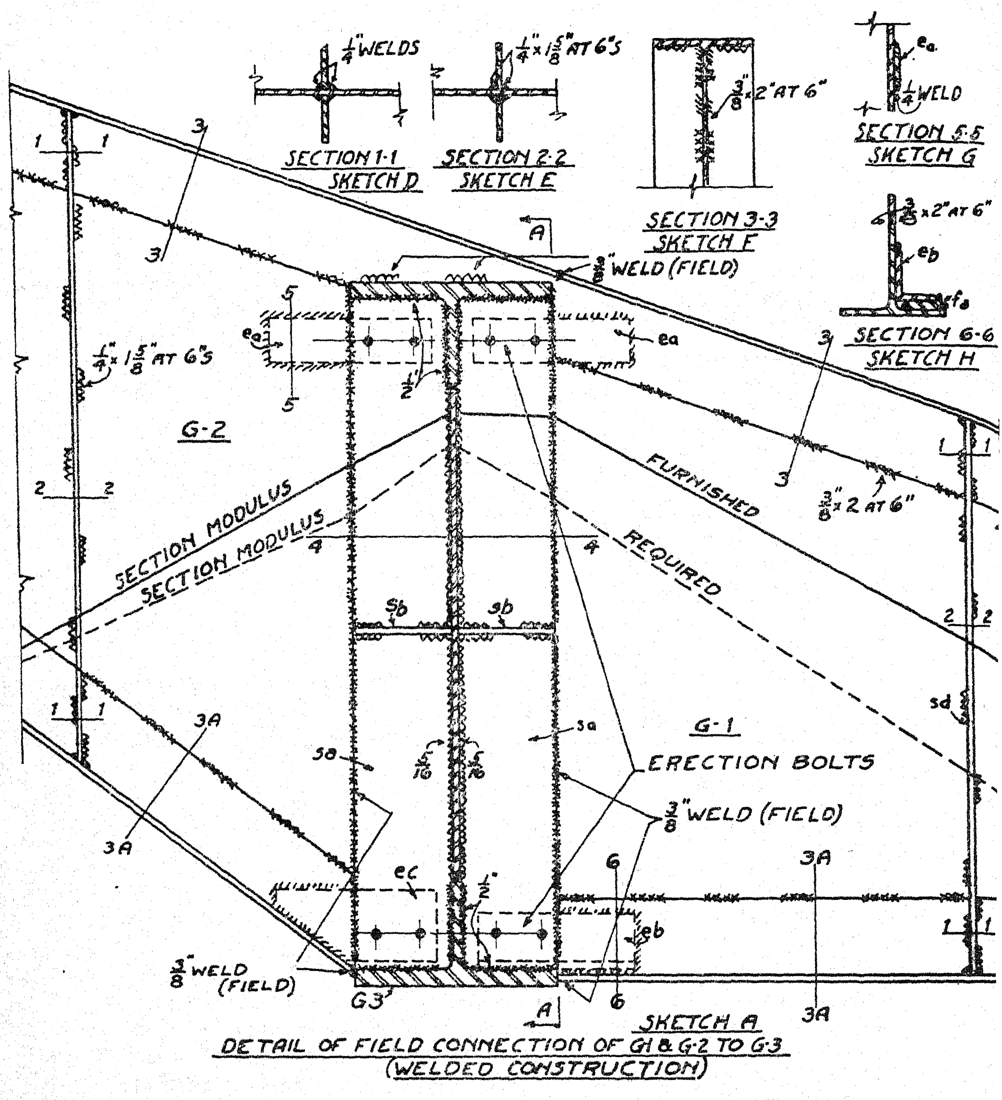
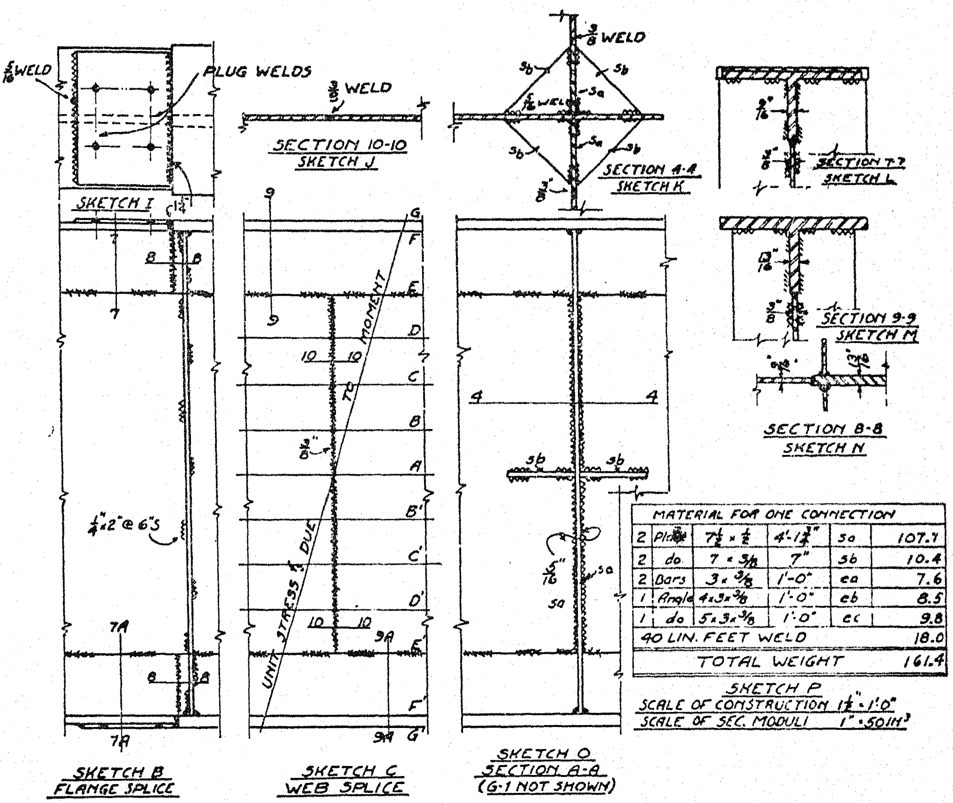


Fig. 4. Field connection of girders. See also page 521b.



MATERIAL FOR ONE CONNECTION					
2	Pl.	7½ × ½	4'-1¾"	5a	107.7
2	do	7 × 3/8	7"	5b	10.4
2	Bars	3 × 3/8	1'-0"	6a	7.6
1	Angle	4×3×3/8	1'-0"	6b	8.5
1	do	5×3×3/8	1'-0"	6c	9.8
40 LIN. FEET WELD					18.0
TOTAL WEIGHT					161.4

Fig. 4. Field connection of girders. See also page 521a.

COMPARISON OF NUMBER OF PIECES OF MATERIAL

	G-1 and G-2	G-3	Field Connection	Total
Welded Construction	44	45	16	105
Riveted Construction	112	75	48	235
Actual Difference	68	30	32	130

Above table gives total number of pieces of material for both types of construction. Riveted construction requires two and one-third (2⅓) times as many pieces as welded construction.

COMPARISON OF OPERATIONS
(Exclusive of Riveting or Welding)

	G-1 and G-2	G-3	Field Connection	Total
Welded Construction	132	46	24	202
Riveted Construction	1976	3515	1159	6650
Difference	1844	3469	1135	6448

Above table gives numbers of shop and field fabrication operations. Riveted construction requires 6650 operations compared with 202 for welded construction.

COMPARISON OF RIVETS WITH WELDS

	G-1 and G-2	G-3	Field Connection		Total		Total Field and Shop
			Field	Shop	Field	Shop	
Welds (Lin. Ft.)	110	198	24	51	24	359	383
Welds (Number)	680	666	18	92	18	1424	1442
*Rivets (Number)	402	850	172	136	172	1388	1560

* Each Rivet involves five elements:
(1) Heating
(2) Passing to Riveter
(3) Inserting in Hole
(4) Bucking Up
(5) Driving

Above table gives a comparison of numbers of individual welds and length of weld in feet with actual number of rivets. It will be noted

that 383 lineal feet of welding is required for all shop and field work, which is divided into 1442 individual welds. For riveted construction, a total of 1560 rivets are required. Mention is made in passing, that for the 1560 rivets, 7800 operations are required. (See elements of riveting at bottom of above table).

COMPARISONS OF COSTS

	G-1 and G-2			G-3		
	Material	Labor	Total	Material	Labor	Total
Welded Const.	126.01	71.65	197.66	324.85	77.90	402.75
Riveted Const.	182.87	190.32	373.19	388.73	212.31	601.04
Actual Difference	56.86	118.67	175.53	63.88	134.41	198.29
% increase riveted const.	45.1%	165.6%	88.8%	19.7%	172.5%	49.2%

	Field Connection			Total		
	Material	Labor	Total	Material	Labor	Total
Welded Const.	14.57	39.54	54.11	465.43	189.09	654.52
Riveted Const.	40.40	119.64	160.04	612.00	522.27	1134.27
Actual Difference	25.83	80.10	105.93	146.57	333.18	479.75
% increase riveted const.	177.3%	202.6%	195.7%	31.5%	176.2%	73.3%

Above table gives comparisons of material costs, labor costs and total costs. From this it is seen that the riveted construction in production cost alone is $479.75 greater than welded construction. Riveted work costs 73.3% more than welded construction.

The consumer's ultimate cost difference is greater than this, since differences in capital charges, cartage, freight, erecting, hoisting, etc., which are greater for riveted than for welded construction, are not taken into account.

One of the principal factors in such saving is in the less amount of detail required for welded construction; a second factor is less shop and erection cost; and a third is the adaptability of design to conditions for most effective use of the material.

This latter factor is forcibly illustrated by a comparison of the connections of G-1 and G-2 to G-3 for riveted construction, and welded construction. For welded construction with a weight of 322.8 lbs. for two connections, compare 1329.8 lbs. for riveted construction. The result is four and 12/100 (4.12) times as much material. Then compare 24 shop operations (exclusive of welding) for welded construction, with 1159 shop operations (exclusive of riveting) for riveted construction. Compare 51 feet of shop welding with 136 shop rivets, 23.7 feet of field welding with 172 field rivets, and, lastly, a production shop and erection

cost of \$160.04 for riveted construction as compared with \$54.11 for welded construction. The riveted construction costs approximately three times as much as welded construction, or 195.7 per cent more than welded construction.

Gross Saving Accruing to the Theatre Industry.—As stated earlier, the seat is the unit of measure in theatres, and all economics, therefore, revolves about this unit.

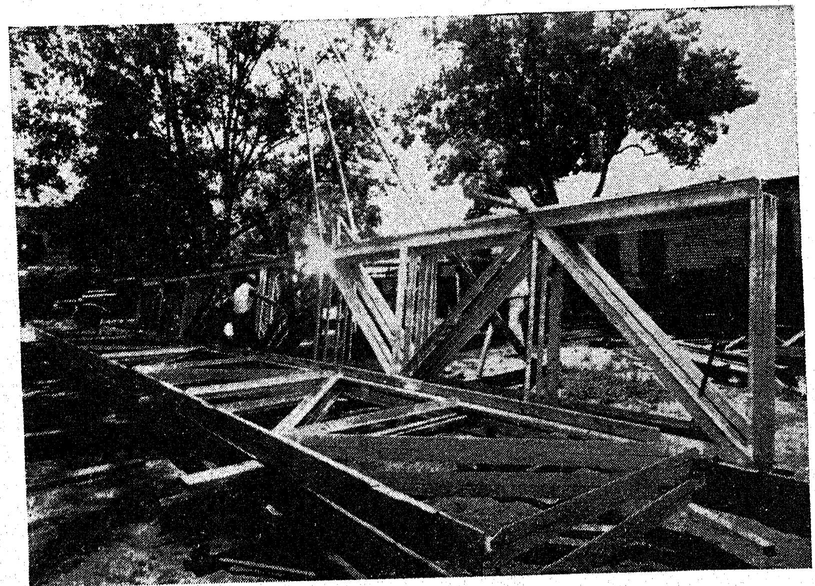


Fig. 5. Fabricating trusses by arc welding.

In the portion of the balcony supported by the foregoing girders, there are 276 seats. The cost, therefore, per seat for supporting steel with welded construction is \$2.37 per seat; with riveted construction, it is \$4.11 per seat; the difference being \$1.74 per seat.

Fig. 5 shows a photograph of trusses being fabricated by arc welding. It will be seen that the welded fabrication is being done on a vacant lot adjacent to the theatre site, the equipment being a welder mounted on a truck.

The weight of trusses and bracing by riveted construction is 5.94 lbs. per square foot of floor area; by welded construction 5.08 lbs. per square foot of floor area, due to saving gussets of trusses, details of bracing and rivets. The cost per square foot for steel trusses and bracing is 5.94 lbs. x 5.37¢ = 31.84 cents per square foot for riveted construction, and 5.08 x 4.12¢ = 20.89 cents per square foot for welded construction. The difference is that welded construction costs 10.95 cents per square foot of floor area less than riveted construction.

The average floor area required to be roofed, including aisles, cross overs, stage space and public space, is about 8.4 square feet for each

available seat so that the saving in cost of roof steel per seat by using welded instead of riveted construction is 8.4 x 10.95 or 92¢ per seat.

Therefore, for auditorium seats, a saving of 92¢ per seat may be expected; for balcony seats, using cantilever framing as hereinbefore described, a saving of $1.74 per seat may be expected.

For a house of 1500 seats, of which 350 are balcony seats, from the above figures, the saving would be:

1150 seats @ 92¢	**$1,058.00**
350 seats @ 1.74	**609.00**
Total	**$1,667.00**

The average construction cost per seat for theatre buildings of ordinary construction may be taken at approximately $55.00 per seat. This would make the above building of 1500 seats cost approximately $82,500.00; the saving above of $1667.00 is approximately two per cent of this total cost of construction.

Two per cent on the entire dollar expenditure for theatre construction in the United States is an item meriting careful thought and consideration by designers and operators of theatres.

Effect on Basic Production of Steel.—Any method which lowers the cost of a finished product without diminishing its quality, broadens its market.

The steel industry as a whole, therefore, should benefit by the economies possible in welded construction over riveted construction, because, while less tonnage is involved in a given installation, the material becomes successfully competitive with other materials such as reinforced concrete and the ultimate tonnage absorbed by the market should be increased. The automobile industry is a good example of lower production and selling cost, with increased total volumes of sales.

Effect on Fabricating Industry.—The trend naturally and inevitably will be toward greater diversity of fabricating units and less shop costs and overhead. Therefore, markets will be broadened and to a larger extent localized on small and moderate work. Business will be placed more and more on a service, rather than a price, basis, and this tends to create better relations between buyer and seller, a higher quality of workmanship, and a better profit margin.

Small Business Man.—The general adoption of welded construction for steel fabrication and erection would open the field to the small business man who does not command sufficient capital to invest in heavy fabricating machinery, and large and expensive buildings, which are required for riveted construction. Such a condition would tend toward decentralization of industry in respect of fabricating, and would materially increase the number of owner-operated plants. Local banks and other commercial and business houses in the respective communities would be favorably affected and the result would be a healthy restoration of individuality in industry and business.

Skilled Labor as a Class.—More skilled labor is used in welded construction than in riveted construction. With the system of grading

welders and classifying as to quality of work on which they have proven their ability, there is an incentive for each welder to improve his work and advance to the next higher bracket.

Welders earn, by reason of the skill required, relatively high rates of compensation and, therefore, are enabled to maintain a higher standard of living and, therefore, make better citizens, than those persons who are capable of earning only a meagre wage and are compelled to live in comparative poverty.

Individual Skilled Worker.—By reason of the two next preceding factors, decentralization of industry and good wages, the individual worker benefits in three distinct ways:

(1) He becomes a human part of the organization which he serves instead of a robot. His work is such that it may be more readily seen by his employer and therefore greater appreciation for good work can be shown. This creates a better employer-employee relationship.

(2) Shop work and income from factory employment may be supplemented by agricultural work and husbandry. The family vegetables and fruits may be produced for fresh supplies, and the surplus canned for off-season consumption; and the family supply of chickens, eggs, butter and milk may be provided. By this method of producing a large part of the food products required, the family unit is made secure against effects of industrial depression.

(3) Such surroundings and conditions tend to produce more contentment, insure family harmony, create neighborhood fellowship, establish economic independence and secure better citizenship among all persons so situated.

And if no other benefits than these last should accrue, the welfare of the nation would be greatly improved.

Chapter VI—Application of Arc Welding to Single-Frame Structures for Single or Multiple Dwellings

By S. Fraser McIntosh,
Vice president, Insulated Steel-Built Structures, Inc., Amsterdam, N. Y.

Desirable features made possible by the use of arc welding in the construction of single and multiple dwellings under the system described in this paper are:

(1) Non-shrinking structural members; (2) elimination of plaster cracks; (3) ease of fastening of materials to frame; (4) simplicity of design; (5) rot and vermin proof construction; (6) standard building materials can be used; (7) simplified installation of heating equipment; (8) simplified installation of plumbing equipment; (9) simplified installation of electric equipment; (10) low depreciation; (11) rapid construction; (12) adaptable to any style architecture; (13) maximum shop work; (14) minimum field work; (15) simplified shop detailing; and (16) low shop equipment cost.

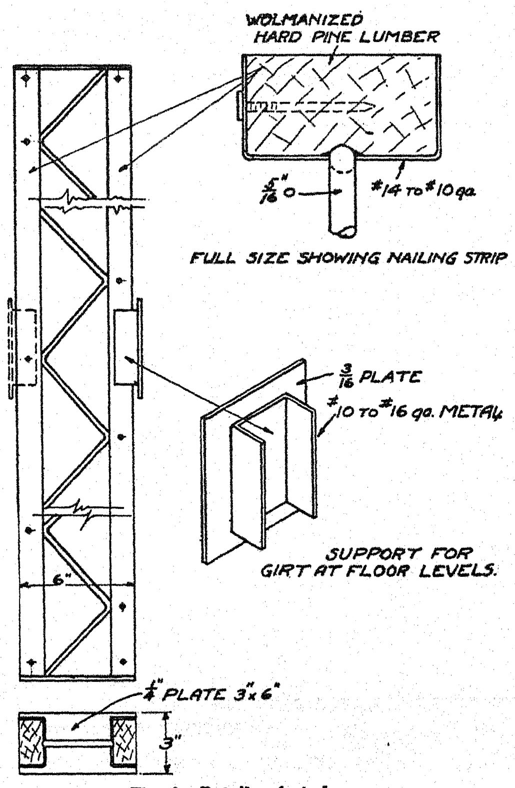


Fig. 1. Details of stud.

Design of Component Parts.—The steel frame described in this paper consists of three major units: (1) the stud; (2) the beam, and (3) the girt. These are shown in Figs. 1, 2, 3 and 4. Reference to these drawings will show the details.

Shop Work.—Arc welding was decided upon for shop fabrication after experimenting with other methods of welding and taking into consideration the cost of equipment and shop time. Some operations could only be done by arc welding.

By using the "Module System" in designing the buildings, shop detailing was eliminated almost completely, as most of the required shop information is covered by listing of parts by numbers in combinations, such as B-12-8-16. This arrangement of numbers is the method of ordering 12 standard beams 8 inches deep for a 16-foot room. The order for 2 standard girts 8 inches deep for a 14-foot room was by this designation:

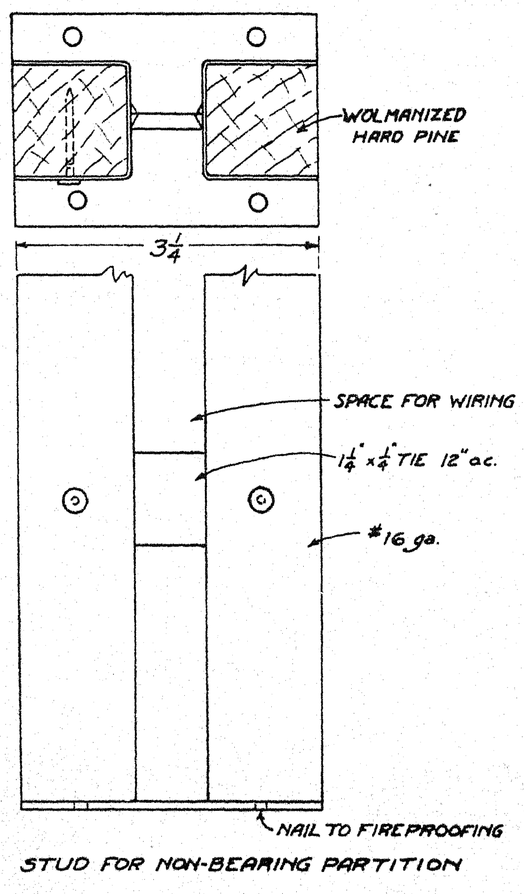


Fig. 2. Details of light stud.

G-2-8-14. SS-40-6-9-9-9′-6″ was the order for 40 single studs 6″ standard for a building with a first-story height of nine feet, second story nine feet, third story nine feet six inches.

If the order had read DS instead of SS it would have called for interior studs with double-beam supports.

Window and door sills and headers are also standard and ordered by listing.

Steel order from the shop by listing as shown above would cover ninety per cent of the required steel for the building.

Figs. 5 and 6 show houses built under this system of design. Particulars are as follows:

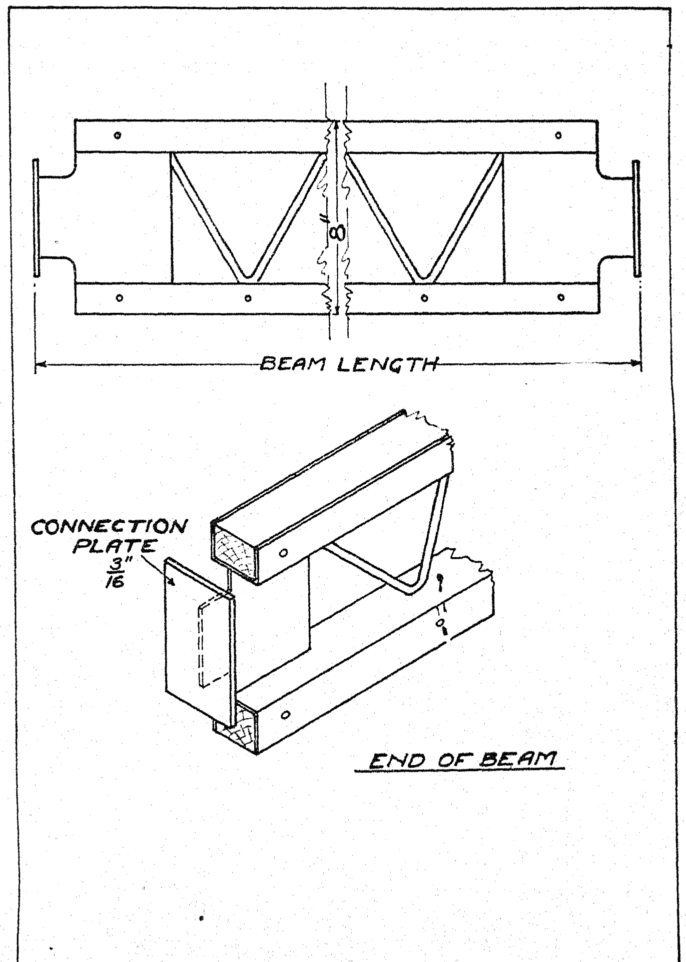


Fig. 3. Details of beam.

HOUSE (FIG. 5) ERECTED IN NORTHERN NEW JERSEY

Cubical contents	45,000 cu. ft.
Steel frame	15 tons
Field welding	140 hours
Welding labor	$2.50 per hour

HOUSE (FIG. 6) ERECTED IN NEW YORK CITY

Cubical contents	30,000 cu. ft.
Steel frame	10 tons
Field welding	120 hours
Welding labor	$2.00 per hour

The cubic-foot price of both houses was the same, 40 cents a cubic foot. The amount of steel in each house was one ton to each 3000 cubic feet. The cost of steel in each house complete, including erection, shop and field painting, and overhead was about $190.00 per ton. The excess cost over prices received for a wooden frame building was less than ten per cent of the cost of the completed building.

No cost comparison between various steel frames can be made without considering what has to be done after the steel is erected to take care of the enclosing materials and other things such as installation of door bucks, grounds for plastering, fastening for wood trim, and nailing strips for finish floors.

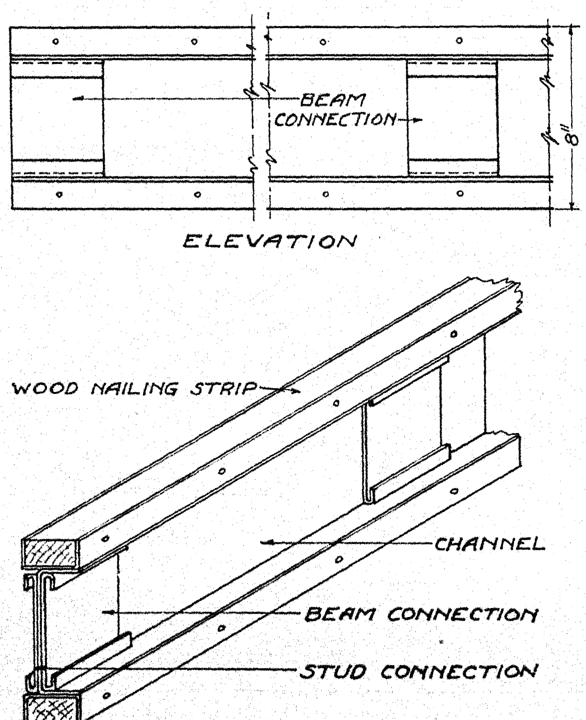


Fig. 4. Details of girt.

All other frames with which we are familiar require a lot of field work to temporarily brace the structure during erection. The frame described here does not require temporary bracing, the connections keeping the frame true and plumb. Also furnished as part of the frame proper are all necessary requirements for fastening of windows and doors, flooring, plaster grounds, interior trim, insulation, etc.

Apartment House Construction.—This is the largest field for steel-frame construction of the type described herein. In apartment house construction, the work is much simpler as usually the roof construction is flat. Hip and valley work is, therefore, eliminated.

In the use of steel framing for private house construction, the cost is always more because wood, a cheaper material, is being replaced by steel, a more expensive material.

Steel frames for small houses will only appeal to the owner who is willing to pay more for a superior article, therefore, the field is limited. However, with apartment house work using the frame described herein we find a different situation.

In apartment house construction, we find that the steel, using our methods, is replacing masonry and producing combined wall and floor construction at a lower price, this results in our being able to build a fire-resisting structure for the same cost or less, as for a wall-bearing type having wood floor joist and wood partitions and no fireproof features.

The field for this work is very large and will become larger as the low-wage industrial worker will eventually be housed in multiple dwellings, single houses being beyond his earning capacity.

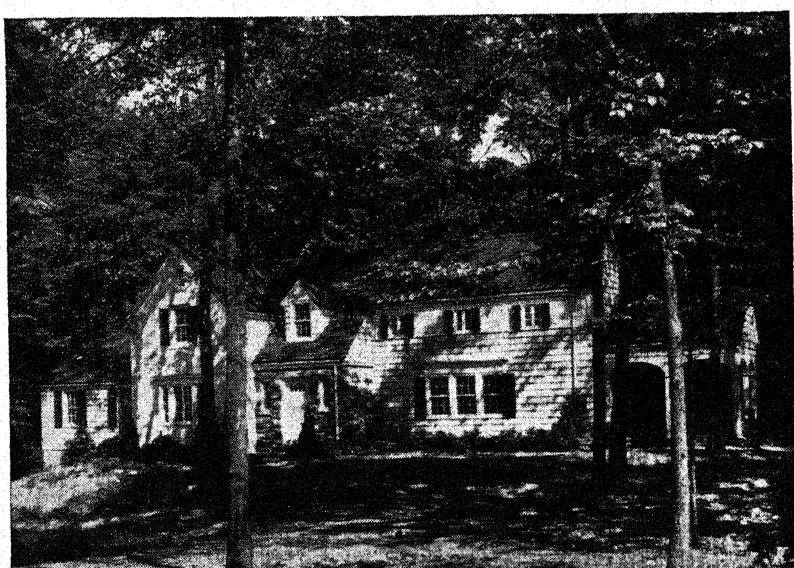


Fig. 5. House of 45,000 cubic feet having arc welded steel frame.

Further, by the use of our steel frame in apartment house construction we eliminate the shrinkage of lumber and this elimination of shrinkage will allow the use of a manufactured plaster board erected in such a way that no cracking of plaster will occur. We will have a wall superior to a lath and plaster wall.

Plastering will not be necessary and the time required to construct a building will be reduced by as much as twenty per cent.

This elimination of plaster work has been worked out and been approved by some of the leading architects in the country.

Fig. 6. House of 30,000 cubic feet having arc welded steel frame.

COMPARATIVE COSTS

(See drawing, Fig. 7.)

Cost of old-type wall, no fireproofing features.

Face brick	.42 sq. ft.
Back-up brick	.58 sq. ft.
Waterproof coating	.03 sq. ft.
Wooden wall furring	.03 sq. ft.
Wire lath and plaster	.13 sq. ft.
	$1.19 sq. ft.

Cost of new-type wall, 3 hour rating, fireproof.

Face brick	.42 sq. ft.
Waterproofing	.02 sq. ft.
Wall ties, special	.03 sq. ft.
Insulation, fireproof	.12 sq. ft.
Steel	.16 sq. ft.
Lath and plaster	.13 sq. ft.
Reflective insulation	.03 sq. ft.
	$ .91 sq. ft.

(See drawing, Fig. 8.)

Cost of old-type floor construction, wood.

Finish flooring	.16 sq. ft.
Sub-floor	.06 sq. ft.
Wood floor beams	.08 sq. ft.
Bridging	.02 sq. ft.
Furring	.03 sq. ft.
Wire lath and plaster	.13 sq. ft.
	$ .48 sq. ft.

Cost of new-type floor, four hour rating.

Finish flooring	.16 sq. ft.
Sub-floor	.06 sq. ft.
Fireproofing	.14 sq. ft.
Steel	.15 sq. ft.
Wire lath and plaster	.13 sq. ft.
	$ .64 sq. ft.

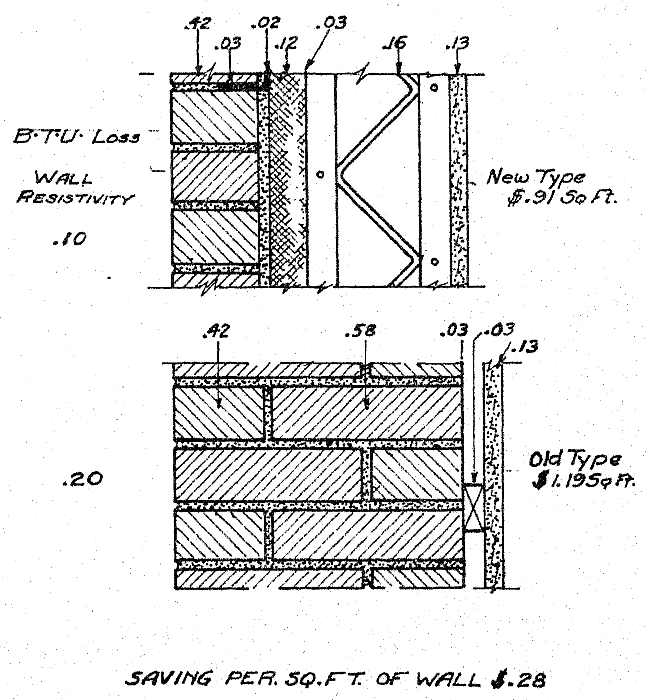


Fig. 7. Savings in cost by new type construction (wall section).

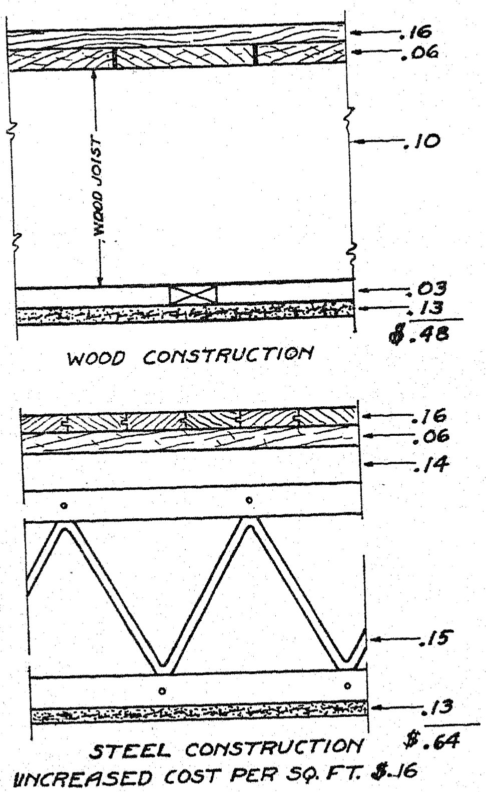


Fig. 8. Comparisons—wood and steel construction (floor section).

The following areas are from the plans of a large three and four story apartment for erection under F.H.A. insurance requirements in northern New Jersey.

Wall area less window surface		80,620 sq. ft.	
Floor area		101,680 sq. ft.	
Exterior wall saving per sq. ft.	$1.19—	.91	$ .28
Floor area additional cost	.64—	.48	$ .16
Saving	80,620 x .28		$22,573.60
Extra	101,680 x .16		16,268.80
Net saving			$ 6,304.80

We can produce a fire-proof apartment for $6,304.80 less than it would cost to build it non-fireproof, and we will have an insulated building requiring twenty per cent less heating equipment. Arc welding has made this possible.

Chapter VII—Welded Steel Frame for Residences

By MYRON T. HILL,
Architect, Toledo, Ohio.

Out of a maze of conflicting depression cures and economic programs there stands one paramount issue generally endorsed by all—a sorely needed revival of home building throughout the nation. Legislators, knowing the tremendous home shortage that has accumulated during the past eight years, have sought laws to solve the problem. Bankers have grappled with the need of again making sound investments in new residential construction. Industrialists, sensing a great potential market, have played with countless schemes of pre-fabricated units of construction. Architects and engineers of the nation, vitally and intensely interested in a solution of this problem, have directed a searching query as to what type of dwellings will best answer the present need . . . and which we will presently see rising in the cities and on the farms of this country!

It has been the privilege of the writer to have been associated in the design of "Hearthstone", a home of unusual size in Ottawa Hills, Ohio, which in its design and use of materials may well be indicative of the present trend in American home-building. This home was completed in April, 1937 and has been occupied slightly over one year.*

The owner of "Hearthstone", in collaboration with the architect, set up certain rather definite provisions for the project. The house, due to its distant location from adequate fire protection, was to be as fireproof as practicable. The exterior was to be of stone in the Georgian style. The main rooms were to be of ample size and well lighted. All floors were to be finished in mosaic tile; and the heating, plumbing, and electrical installations were to be as advanced as possible.

Architecturally, the design has answered this program with a richly textured stone veneer in pleasing contrast with the Georgian white wood trim and entrance motif. A stone parapet is backed with a low sloping roof of dark slate and topped off with generous stone chimneys. The plan is L-shaped, each arm of the "L" being over one hundred feet in length.

The home is luxuriously complete in its living plans. The basement includes a motion picture room and recreation room in addition to the usual heating, laundry, and drying facilities. The first floor has a large solarium, a living room and dining room, each nineteen by twenty-nine feet, a library, morning room, large stair hall, kitchen and several rooms for servants. The second floor comprises another large solarium, four large bedrooms with private baths, a fern room, an upstairs kitchen and service room, in addition to servants' quarters. Garage space for four cars and a gardener's shop are located at the extreme rear of the service wing.

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*At time paper was written.

The exterior of the house is Bloomville, Ohio limestone veneer, colored buff to gray, rock and bed-faced. Basement walls are of load-bearing tile on concrete footings. Double-hung wood windows, glazed with plate glass, are used throughout. The entrance motif is two stories high, beautifully detailed in wood.

Walls of the living room, dining room, library, recreation room, and four bedrooms are finished in wood panelling; ceilings are canvas-covered plaster with wood cornices. Floors of all rooms except servants' quarters are glazed mosaic tile. Linoleum is used in the service portion. The stair hall floor and stairs are of marble, with walls of imported Roman travertine.

Heating is provided with an oil furnace, two boilers, split system, with conditioned air to all main rooms and bedrooms. Ducts have been installed and provision made for a future cooling system. Zone control of servants' quarters and garage is provided by motor-operated steam valves. Copper tubing has been used for hot and cold water piping. A phone system has been installed with outlets at convenient locations.

During the process of studying the architectural planning, comparative designs of both floor and wall construction were made and submitted to impartial residential contractors for cost data. The walls considered were:

(1) Stone veneer, welded steel studs, metal lath and plaster;

(2) Stone veneer with haydite back-up, wood furring, metal lath and plaster.

(3) Stone veneer with brick back-up, wood furring, metal lath and plaster.

As shown in Fig. 1, the stone veneer with welded steel frame (1) was considerably less expensive and rated higher in coefficient of heat transmission.

The floor systems, (See Fig. 2), judged were:

(1) Steel joists;

(2) Steel beams of a welded frame;

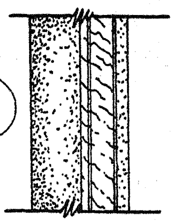
(3) Concrete slab and beams.

All of these rough floors were surmounted by a cement fill and tile finish floor, the steel floor members of (1) and (2) requiring an additional structural concrete top slab. The steel beams (2) were slightly higher in cost than the steel joists (1), but due to their greater rigidity and ready incorporation with the wall frames, the choice was made for welded steel beams (2). (See Fig. 2.)

For the walls of "Hearthstone" a five-inch stone veneer, set in waterproof mortar and back plastered with waterproof cement mortar, is set with one-inch air space outside the three-inch standard channel studs. On the interior of the studs, metal lath and plaster are used, the space from lath and plaster to stone veneer being filled with waterproof, mineral wool insulation. The coefficient of heat transmission for this wall is approximately 0.062.

Floors are constructed of eight-inch channels or beams, spaced three feet to three feet six inches on centers, covered with a rib lath upon which two and one-half inches of concrete are poured. Tile is bedded and set upon this; areas to be covered with linoleum are finished with

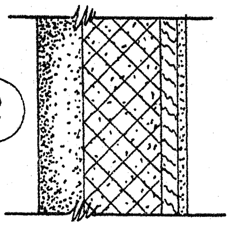
1



Stone veneer	.60
Welded steel frame	.25
Metal lath	.06
Plaster	.08
3½" Insulation	.12
	$1.11 per square foot

Coefficient of Heat Transmission = 0.062

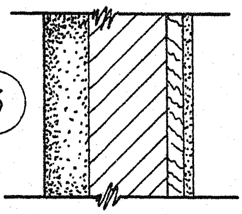
2



Stone veneer	.60
8" Haydite	.36
Wood grounds	.09
Metal lath	.06
Plaster	.08
2" Insulation	.08
	$1.27 per square foot

Coefficient of Heat Transmission = 0.11

3



Stone veneer	.60
8" Brick	.64
Wood grounds	.09
Metal lath	.06
Plaster	.08
2" Insulation	.08
	$1.55 per square foot

Coefficient of Heat Transmission = 0.11

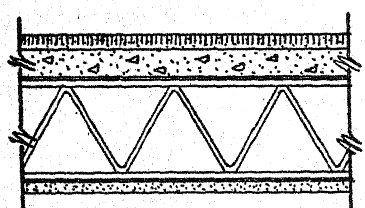
Fig. 1. Comparative wall systems.

a steel trowelled surface. Wood floor can be used either in mastic or nailed to sleepers set in the concrete. Metal lath and plaster on the bottom of the floor members furnish the ceiling for the rooms below. A complete floor was poured at first, second and third story levels; the sloping roof was framed in wood.

The structural design included one-quarter inch scale framing plans of all floors and three-quarter inch scale shop details of all wall steel.

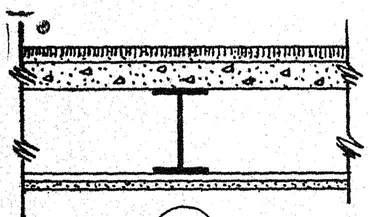
The walls are composed of large shop-welded panels, one story in height, using standard three-inch channels as studs, and angles, plates, etc., as necessary. All wall panels were detailed to be less than ten by eighteen feet in size so that they could be hauled safely by truck from the assembly shop to the site. The largest panels weighed less than five hundred pounds, so that four men were able to handle the erection with only a small A-frame made of four-inch timbers on the job.

Bearing plates were set by instrument to level on top of the basement wall. First floor wall panels were then placed and temporarily bolted together. First floor beams and channels were placed, then all first-story steel was aligned and welded. A continuous girt angle on the



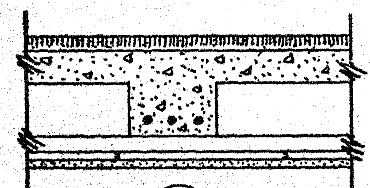
1

Tile floors	.65
$2\frac{1}{2}$" Concrete	.08
10" Steel joist	.19
Metal lath on top	.08
Metal lath ceiling	.07
Plaster	.11
	\$1.18 per square foot



2

Tile floors	.65
$2\frac{1}{2}$" Concrete	.08
8" Beams	.19
Metal lath on top	.09
Metal lath ceiling	.09
Plaster	.11
	\$1.21 per square foot



3

Tile floors	.65
3" Conc. slab and 8" Beams	.12
Forms	.24
Reinforcing steel	.13
Metal lath ceiling	.11
Plaster	.11
	\$1.36 per square foot

Fig. 2. Comparative floor systems.

inside of the first story wall panels supports the second floor beams, which were next placed. Second story wall panels were set and beams and panels welded. Wherever possible, first story studs extend up to the lower girt of the second story, and second-story studs extend down to the upper girt of the first-story panels. This procedure guarantees a continuity of structure and tremendously increases the rigidity of the frame. Third floor beams are finally placed and welded.

The total erection of the forty-five tons of steel required ten working days for four union structural iron workers and a foreman. Field welding is of necessity an intermittent process and required one welder most of the ten days.

All welding, whether in shop or field, was done with the electric arc process, using a portable welding machine driven with a gasoline motor for the field work. Coated electrodes were used throughout. One-quarter inch fillet welds were used almost entirely. Field welding was kept at a minimum as the cost is approximately three and one-half times that of shop welding.

By the use of girt angles on the inside of the wall frames as support for floor steel, no interference is encountered in placing pipes, ducts, and conduits. All exterior studs are securely fastened to the stone veneer at regular spacing to provide mutual stiffening. Interior wall studs have horizontal tie-straps.

Forty five tons of steel were used, 63 per cent in the floors, 34 per cent in the walls, and 3 per cent in loose lintels. A breakdown of the steel frame costs is as follows:

FLOORS

First	4016 sq. ft.—	15,400 lb. @	$ 92.81/ton—	$ 715.00
Second	5338 sq. ft.—	20,800 lb. @	92.81/ton—	965.00
Third	4383 sq. ft.—	19,400 lb. @	92.81/ton—	900.00
Total	13737 sq. ft.—	55,600 lb. @	92.81/ton—	$2580.00

WALLS—INTERIOR

First Story	2240 sq. ft.—	6,485 lb. @	$185.55/ton—	$ 600.00
Second Story	1503 sq. ft.—	4,302 lb. @	185.55/ton—	400.00
Total	3743 sq. ft.—	10,787 lb. @	185.55/ton—	$1000.00

WALLS—EXTERIOR

First Story	3536 sq. ft.—	9,295 lb. @	$185.55/ton—	$ 861.40
Second Story	3578 sq. ft.—	9,918 lb. @	185.55/ton—	922.00
Total	7114 sq. ft.—	19,213 lb. @	185.55/ton—	$1783.40
Clips		500 lb. @	$185.55/ton—	46.40
Loose Lintels		4100 lb. @	92.81/ton—	190.20
GRAND TOTAL		45.1 tons @	$124.00/ton—	$5600.00

STEEL COSTS

Erection	45.1 tons	@ $21.95/ton—	$ 990.00
Shop Paint	45.1 tons	@ 4.66/ton—	210.00
Field Paint	45.1 tons	@ 4.66/ton—	210.00

Material Costs and Shop Work

First Floor	15,400 lb.	
Second Floor	20,800 lb.	
Third Floor	19,400 lb.	
Lintels	4,100 lb.	
	59,700 lb. @ $ 56.00/ton	$1671.60
Exterior Walls	19,213 lb.	
Interior Walls	10,787 lb.	
Clips	500 lb.	
	30,500 lb. @ $148.74/ton	$2268.40
Field Welding	45.1 tons @ $5.54/ton	250.00
GRAND TOTAL	45.1 tons @ $124.00/ton	$5600.00

A comparison of the unit costs of the various wall and floor systems is as follows:

	Cost per sq. ft.	Per cent savings of welded frame
WALLS		
Welded steel frame	$1.11	Base
Haydite back-up	1.27	12.6
Brick back-up	1.55	28.5
FLOORS		
Steel joists	$1.18	−2.5
Welded steel frame	1.21	Base
Concrete slab and beams	1.36	11.0

A comparison of the total costs of the exterior walls and floors using the different possible combinations is as follows:

				Per cent savings of welded frame
Welded steel walls	7114 x	$1.11 —	$ 7,900	
and floors	13737 x	1.21 —	16,600	
			$24,500	Base
Haydite back-up	7114 x	$1.27 —	9,050	
and steel joists	13737 x	1.18 —	16,200	
			$25,250	2.98
Haydite back-up	7114 x	$1.27 —	9,050	
and concrete slab and beams	13737 x	1.36 —	18,700	
			$27,750	11.7
Brick back-up	7114 x	$1.55 —	11,000	
and steel joists	13737 x	1.18 —	16.200	
			$27,200	9.9
Brick back-up	7114 x	$1.55 —	11,000	
and concrete slab and beams	13737 x	1.36 —	18,700	
			$29,700	21.2

Improved design and construction standards for schools, apartments, public and commercial buildings have had a definite part in making the average American contemplate the possibility of making his home safe from fire and of sound construction. Insurance companies have aided in promoting fireproof dwellings. More recently, the United States Government, through its Federal Housing Administration, has sought

to encourage and through its Housing Division has actually constructed many fireproof modern living units. Today, the consideration of fire-resisting construction for home building is of a more serious nature than at any previous time in our American history.

"Homes of steel" has been a handy phrase for speakers and writers these past few years, expressing in a general way what we may find before us. But to many this phrase has painted an interesting picture. . . . To the home owner it has been a dream that provides a possible meeting place between the luxury of his home wants and the economies of his purse. . . . To the steel and iron industry it has been a very real challenge to industrial genius of planned production. . . . To the architectural and engineering professions it has been an intriguing problem, testing inventive ability and a practical co-ordination of architectural beauty and sound engineering principles.

Although forty years have elapsed since the first steel-frame house was built in Brooklyn, progress has been sporadic and unbalanced. Millions of dollars have been spent in ill-advised building ventures, top-heavy with engineering ability but forgetful of architectural co-operation. The large steel companies have spent thousands of dollars in research. They have carefully assembled all available data on the use of steel in residential construction, have watched the swing of opinion regarding the use of rolled shapes, molded flat sheets, or special sections. Most of the large steel manufacturers, however, have been loath to enter the building field as constructors, putting themselves in actual competition with their customers, and have attempted merely to sponsor the use of steel in residences by a limited amount of booklets and magazine advertising.

The most important advances in the use of steel for homes have been made by a scattered number of individual designers. Many of these have developed fairly economical systems of construction, then, fearful of uncontrolled competition, have patented their particular method of design, detail, or system of erection. Thus, they have effectively stopped competition, but in most cases have just as effectively shut themselves out of the business of building.

Engaged in one of the most highly competitive industries in existence, building contractors have almost universally avoided these patented types of construction and have clung to standard building methods and materials. Until a method of steel-frame construction can be devised that will offer economy of construction, ease of assembly and erection, and freedom from patent interference, there is little chance of its general acceptance by the builders of the nation.

To the engineering profession, the acceptance of the use of steel in homes should mean the greatest single broadening in the scope of the profession since the introduction of reinforced concrete. More costly than wood, the economic use of steel requires higher unit working stresses in the material. No longer is a carpenter qualified to determine floor joists, lintels, beams, columns, etc., but this becomes the logical duty of the engineer.

An attempt has been made with "Hearthstone" to design a logical steel frame, economical and efficient, free from special patented features, yet not interfering with the established architectural design. This is essentially an individual design and no attempt has been made to

standardize wall or floor sections. On a program of buildings using repetitive units in plan or elevation an ordered system could be used at a great saving over this example.

To industry the welded steel frame for residences is laden with possibilities for the future. In a smaller panel form it may come to the site of the proposed home with exterior and interior wall surfaces factory attached. Plumbing, heating and wiring may be included within each panel, or more likely in special key panels. Windows and doors may be ready for use as they are set into place. The system could be easily extended into the field of commercial and industrial building.

Public acceptance alone is the key which will unlock this treasure house; and public acceptance will be swayed largely by three essentials:

(1) The new construction must be at a savings over comparable present construction;

(2) The quality of the new building must be superior to that of the past; and

(3) The design must be of an accepted architectural quality.

We have tried to answer the first essential with the cost analysis of comparative systems included in this paper. We believe that the fireproof construction, free from shrinkage and settlement cracks, well insulated, vermin-proof, and with a minimum of maintenance, is of a decidedly higher quality than found in normal American housing. We believe that the architectural design of "Hearthstone", expressing in American feeling and materials the cultured restraint of English Georgian precedent, will find a ready acceptance today.

Chapter VIII—Arc Welded Steel Plate Floors Applied to Bridges and Viaducts

By NED L. ASHTON,
Designer, Ash, Howard, Needles and Tammen, consulting engineers, Kansas City, Mo.

The purpose of this paper is to present a new type of arc welded steel plate floor as shown on drawings, Figs. 1 to 4 inclusive, and to show how steel can be put to many more efficient uses. These additional uses greatly increase the economy of such a structure and broaden it so greatly that even the saving in dead load becomes but one of many reasons justifying the high initial cost.

Drawing, Fig. 1 is a perspective drawing of such a floor. It is designed to be fabricated by welding and it is important to note that the economies cannot be accomplished in the same degree by any other process. As portrayed, this floor is drawn for a typical 30-foot interior panel of a modern four-lane through-arched truss or suspension span with sidewalks.

Such a structure, utilizing a modern open-grating floor, is now* under construction over the Passaic River on Route 25 in New Jersey but the immediate problem of application is unimportant. This new floor is equally applicable in any bridge or viaduct structure consisting of single or double roadways either with or without sidewalks.

This New Floor Serves Many Purposes.—Primarily, the checkered steel-plate floor serves first as flooring as it would in any other light-weight floor and therefore it possesses the same advantages as any other to be gained by being light in weight. At the same time, this plate floor furnishes all the top-flange metal for the main stringers and sub-stringers and the stresses from this action are at right angles to the action as flooring and are of small magnitude. The plate also furnishes the top flange metal for the crossbeams and the main floorbeams and these beams greatly stiffen the plate for direct stress actions. It is to be noted, that all of these beams acting in combination with the floor plate are lighter and stronger than they are in any ordinary construction, utilizing independent structural members for each of these parts. The plate also furnishes a horizontal girder of great depth in place of the ordinary braced bottom lateral system and by the provision of suitable end connection details, at L_0 points, the floor plate, stringers and substringers will serve as the bottom chords of the main trusses themselves at stresses only slightly greater than ordinary secondary overstress allowances.

Typical cross sectional and longitudinal section details are shown on drawing, Fig. 2, as proportioned for standard H-20 modern truck train loading. The detailed calculations for these proportions will be used for illustration purposes to show how by designing the flooring for its primary action at less than allowable stresses, the entire area of this

*At time paper was written.

ordinarily inefficient metal is available to act for such other purposes as may seem most desirable.

For instance, if a certain thickness of plate is required in carbon steel at 18,000 lbs./sq. in., that plate can be made of silicon steel and it will be available at 6,000 lbs./sq. in. for other purposes, without exceeding the normal allowance of 24,000 lbs./sq. in. for silicon steel. Such a change as this increases the base cost of the metal by ¾¢ per pound and three pounds give a stress equivalent at 2¼¢ per pound to replace one pound of metal which would cost not less than 6¢ per pound acting separately.

Other factors of strength such as moment of inertia and section modulus are in proportion to the depth cubed or depth squared, so the economic advantages accrue more rapidly in this arc welded floor than is indicated by the direct ratios of unit stress or areas required.

The Primary Action Is as Flooring.—The design calculations for this floor are given on drawings, Figs. 1, 2, and 3.

The roadway surfaces are made of a ¾" thick carbon steel plate with a rolled checkered plate surface on top and smooth underneath. The stems of all stringers, substringers, crossbeams and floorbeams are welded to this plate. Such floor plates are now available. The ¾" thickness is sufficient so that the plate will not warp under the shrinkage of these stringer and substringer welds as would a thinner plate, but for best construction this roadway plate should be rolled with about ½" bevelled projections on the under side of the plate to which the stringers, substringers and crossbeam webs would fit similar to the girder flange sections rolled specially for welded fabrication in European countries at the present time. To fit this construction, a special traffic plate 12 feet wide and with projections at 14-inch centers transversely and at 6-foot centers longitudinally could be rolled to fit any bridge that is a multiple of 12-foot traffic lanes, for this type of construction in the future.

The floor is designed for standard H-20 trucks and a maximum wheel load of 16,000 pounds plus 40% impact. Such a wheel is considered as having an area of contact with the roadway surface equivalent to a 15-inch diameter circle by designers of concrete bridge floors or to have an area 20 inches wide by 6 inches long by designers of open grating roadway floors. The 15-inch diameter circle equals 176.7 sq. in. and 127 lbs./sq. in. load. The 20 in. x 6 in. rectangle equals 120 sq. in. and 187 lbs./sq. in. For either the circle or the rectangle, some part of the area of contact is always directly over a stringer or substringer when supports are spaced at 14-inch centers. In addition to the portion of floor plate directly under the area of contact, adjacent areas within certain limits are available to aid in supporting the load because the one part cannot deflect without simultaneously loading the adjacent portions of plate. The formula for effective distribution for designing concrete slabs is .58 times the span plus twice the diameter of the contact circle. This gives 42-inch distribution. For battledeck floors, four times the clear span is recommended for the average stress, and the maximum stress is three times the average.

By using 45° distribution from the center line of span to center

line of support the effective length is determined as 7 in. plus 15 in. plus 7 in. or 29 in. for the circle and 7 in. plus 6 in. plus 7 in. or 20 in. for the rectangle. Designers of longitudinal open grating floors assume the 20 in. wide wheel and 25 in. effective distribution. The 20 in. wide wheel has the smallest area of contact, the greatest intensity of load and the least distribution, so will be used for this design. On this basis the load is 187 lbs./sq. in. on 6 in. loaded length supported by 20 in. effective length of the floor plate. The plate span is perpendicular to traffic.

The stress in the floor plate will vary somewhere between a simple span condition and a fixed-ended span condition. To agree with conventional practice, stresses will be computed for 50% fixed-end restraint. As a simple beam, the moment equals $.125wl^2$ at the center. As a fixed-ended beam, the moment equals minus $.0833wl^2$ at the ends and plus $.0467wl^2$ at the center. The average of $.125wl^2$ and $.0467wl^2$ is $.0833wl^2$ at the center for 50% end restraint.

The total load on the 20 in. of floor plate consists of 6 in. of live load at 187 lbs./sq. in. and 20 in. of dead load for a total of 1,125 lbs./in. of span. The span is 14 in. The moment is 18,400 in. lbs. sq.

$$\text{The stress} = \frac{18{,}400\text{x}6}{20\text{x}75^2} = 9{,}800 \text{ lbs./sq. in.}$$

This is the bending stress on the ¾″ plate considered as a beam 20 in. wide, due to the primary action as a floor plate.

The thickness of plate required for flooring alone as designed for one-way slab action at right angles to traffic is only $^9\!/_{16}$ inch.

$$t = \sqrt{\frac{18{,}400 \text{ in. lbs.} \times 6}{20 \times 18{,}000 \text{ lbs./sq. in.}}} = .55 \text{ or } {}^9\!/_{16} \text{ inch.}$$

By adding the additional $^3\!/_{16}$ in. of depth, the stresses in the plate have been reduced from 18,000 lbs./sq. in. to only 9,800 lbs./sq. in. and 8,200 lbs./sq. in. is available in the ¾″ carbon steel plate for other action. This plate can also be made of silicon steel and then 24,000—9,800 or 14,200 lbs./sq. in. of its allowable stress would be available for other purposes. This discussion will be confined to the ¾″ thick carbon steel plate.

The Floor Plate Serves as the Top Flange of the Substringers.—The substringers are designed on the basis of using the ¾″ carbon steel floor plate as the top flange. Experiments on battledeck floor systems performed at Lehigh University have proven that as high at 34 times the thickness of the floor plate can be safely counted as tee flange. The amount of plate in action is independent of the load. The stringers are spaced at fourteen-inch centers so the top flange is counted as a 14″x¾″ plate.

The substringer span is 6 feet center to center of crossbeams. The crossbeams are butt welded together and are made fully continuous in construction. For fabrication, it is intended to flame-cut or stamp, tee-shaped holes through all the crossbeam and diaphragm webs and thread each substringer continuously through all diaphragms. The stems are then welded solidly back together again with single vee or double vee welds extending clear through the crossbeam web metal so as to leave

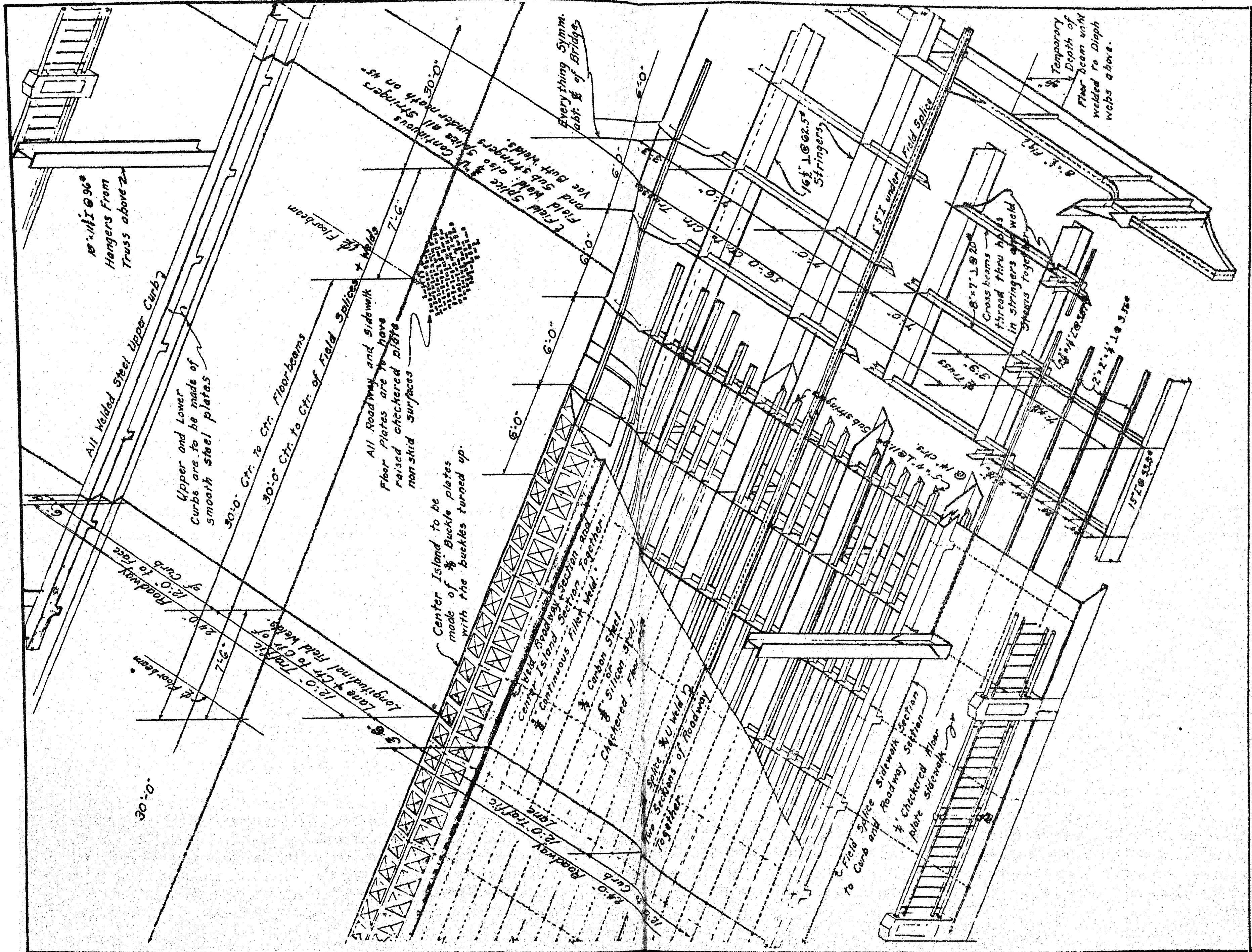


Fig. 1. Perspective drawing of arc welded steel plate floor.

no voids in the intersection. This framework of stringers, crossbeams and substringers is to be thus completely assembled before applying it to the floor plate for welding of the beam webs to the floor plate.

The recommendations of the A.I.S.C. for battledeck floors is: each substringer shall be designed to support one half of a full wheel load. Although this is conservative, the design is made on this basis since deflection calculations to justify the use of a smaller amount are quite lengthy.

The deepest light weight standard tee that seems to be available at the present time without using thinner than 5/16″ metal is the 5″ deep by 4″ wide ⊥58 section @ 11.9 lbs./ft. This tee has 3/8″ to 7/16″ stem and flange. This provides a section modulus of 10.9, which is greater strength than required but desirable for use. The properties of the combined section are computed on drawing, Fig. 3.

The stresses on this section are 4,600 lbs./sq. in. in bending in the floor plate and 15,100 lbs./sq. in. in the bottom flange.

This additional stress is very small and it acts at right angles to the span of the floor plate so it can be combined with but little increase in unit stresses. The combination in the floor plate is

$$\frac{9800}{2} \text{ plus } \frac{1}{2}\sqrt{9800^2+4\text{x}4600^2} = 11{,}625 \text{ lbs./sq. in.}$$

The connection of the tee web to the floor plate is determined by the intensity of horizontal shear on the weld.

The statical moment of the 14″ x 3/4″ plate about the neutral axis is 10.5 sq.″ x .965″ or 10.1 sq. inches squared.

The vertical shear is 11,400 lbs. and the unit shear 2,400 lbs./in.

This equals 6,400 lbs./sq. in. shearing stress on the 3/8″ web and requires a 3/8″ continuous single Vee weld to the floor plate.

This weld should extend clear through the 3/8″ web of the tee and the root of the weld rewelded from the other side to prevent incipient cracks.

This completes the substringer design.

The Floor Plate Serves as Top Flange for the Crossbeams.—The crossbeams are spaced at 6′—0″ centers and span 7′—0″ center to center of main stringers. They span perpendicular to the direction of traffic. The section modulus required is 27.3 at 18,000 lbs./sq. in.

Thirty-four times the thickness of the 3/4″ floor plate or 25½″ is available to use as crossbeam flange in combination with the 8″ x 7″ tee @ 20 lbs. This section is shown on drawing, Fig. 3. It provides a section modulus of 33.2 and the stresses are 4,160 lbs./square inch in the plate and 14,800 lbs./sq. in. in the bottom flange for the given loads.

Again the stress in the floor plate is very low as compared to its capacity. The maximum shear in the crossbeam is given as 27,900 lbs. on drawing, Fig. 3. This figure was determined by placing the edge of one wheel close to the support and another wheel of a second truck at 4′—0″ centers from the first wheel with the crossbeam acting as a simple span. The value given is conservative since the crossbeam cannot deflect without being supported from the adjacent crossbeams by all the longitudinal substringers.

The statical moment of the floor plate about the neutral axis is 19.10 x 1.545″ or 29.5. The unit shear on the weld to the floor plate is 3,600 lbs./sq. in.

The web thickness is .307″ and the unit stress of 11,800 lbs./sq. in. is allowable on the weld metal in shear. A single V weld will be used, built out with filleted corners slightly thicker than the $\frac{5}{16}''$ plate and welded clear through the web of the tee with the root rewelded with a small fillet far side.

At floor beams, the crossbeams are replaced by the web of the floor beam itself.

The Floor Plate Serves as the Top Flange of the Main Stringers.— The typical interior roadway stringers are designed as continuous beams over, or rather through, the floor beams at 30′ centers and they are spaced at 7′—0″ centers transversely.

The dead load is only 51 lbs./sq. ft. of deck including the stringer and totals 360 lbs./lin. ft. of stringer. Including 15 lbs./sq. ft. future paving, the future dead load is 465 lbs./lin. ft.

The design moment is 265,350 ft. lbs. and the shear is 52,300 lbs., as shown on drawing, Fig. 3, and the section required is 176.5 at 18,000 pounds per square inch.

The stringer section consists of two adjacent substringers and 28″ of the $\frac{3}{4}''$ floor plate flange welded to a 16$\frac{1}{2}''$ tee @ 62.5 lbs. cut from a 33″ I beam @ 125 lbs. This section is conservative since .18 times the span length, or 64 inches of the $\frac{3}{4}''$ floor plate, could have been counted as the effective width of the thin wide flange according to the derivation given in Timoshenko's "Theory of Elasticity".

This section provides a section modulus of 181 and the stresses are 9,150 lbs./sq. in. in the floor plate and 17,600 lbs./sq. in. in the bottom flange. The bottom flange of the substringer is practically at the neutral axis so it will be at neutral stress as far as the main stringer action goes.

The combined stress for action as flooring, substringer and main stringer is now determined as

$$\frac{9150+4600}{2} = 6{,}875 \text{ plus } \tfrac{1}{2}\sqrt{13{,}750^2+4 \times 9800^2} \text{ or } 18{,}835 \text{ lbs./sq.in.}$$

This only slightly exceeds the normal allowable stress of 18,000 lbs./sq. in. for carbon steel. If the 64″ x ¾″ floor plate were counted as flange, these stresses in the plate would be very much reduced.

The .57″ web has a unit shear of 3,300 lbs./in. as determined from the statical moment of 127.6. This equals 5,800 lbs./sq. in. on a ⅝″ continuous single vee weld of the web to the floor plate. The root of the weld should be rewelded and the weld should extend clear through the web with solid weld metal. Both the floor plate and stringer sections run continuously over the temporary depth of the floor beams to splice at the quarter points 7′—0″ beyond by butt welding at these points of minimum stress. This continuity of stringers completely eliminates the age-old problem of flexure on riveted end connection angles and eliminates this prolific source of fatigue failures.

The outside roadway stringer is common to both the roadway and sidewalk. It receives only 8/12 as much loading from the roadway live load as an interior stringer so the combined sidewalk and roadway loading on this outside stringer is no greater than for the roadway loading alone on the interior stringers.

The Curbs.—The crossbeams are turned up vertically at the curbs to supply the curb supports and are made into an I section by the addition of a 7″ x ½″ vertical plate flanges on the roadway side of the web. The crossbeam web extends inside to the top and the flanges weld flush into the sides of the upper curb as can be seen on drawing, Fig. 1. The sidewalk and lower curb are also supported from the same vertical crossbeams by a continuation of a lighter 5″ x 4″ T @ 11.9 lbs. to the 15″ fascia channel. The lower curb consists of a horizontal 18″ x ⅜″ smooth structural plate, with I-shaped holes stamped to fit over the vertical curb supports, welded to a 6″ x ⅜″ face plate, set so the vertical face is battered about 1″ in the vertical height of curb. These two plates form an 18″ x 6″ x ⅜″ angle section which is welded solidly to the vertical curb supports, with ⅜″ single V welds all around each post and to the webs of the sidewalk crossbeams which are spaced at six-foot centers underneath. The upper curb consists of two 7″ x 4″ x 7/16″ angles made into an 8″ by 7″ channel section by welding the two 4″ legs together. This section is also welded to the vertical 8″ by 7″ I beam supports at each crossbeam. The curbs are to be shop fabricated in 30-foot sections attached to the adjacent sections of roadway so as to erect as a single unit in the field. The 7″ vertical legs of the upper curb butt weld directly to the 7″ vertical flanges of the curb supports and are to be ground smooth after welding. The webs of the vertical sup-

ports furnish diaphragms at 6′—0″ centers in the 8″ x 7″ channel curb and are to be welded all around inside, while the upper curb is in an upside-down position in the shop, before it is threaded through the holes in the lower curb plate. Following this operation the lower curb is also added in an upside-down position before the whole double curb unit is attached to the roadway unit by making the 45-degree miter joint between the vertical curb support, the horizontal roadway crossbeams and the floor plate, as shown on drawing, Fig. 2. These curbs both have clear open spaces underneath excepting only the points of support which will greatly facilitate the natural removal of snow or other debris from the surfaces of the roadway and sidewalk by the wind.

The Sidewalk.—The sidewalk is of much lighter construction than the roadway. It is designed for 100 lbs./sq. ft. uniform live load, while the roadway is designed for heavy concentrated wheel loads. The details are shown on drawing, Fig. 1. It consists of 1/4″ checkered sidewalk plates welded to 2″ x 2″ 1/4″ Tee stringers spaced at 24 inch centers. This very thin floor plate is fully capable of supporting an ordinary automobile wheel load at normal stress. It would also make an excellent light weight floor for warehouse purposes.

This sidewalk provides considerable excess in strength above requirements for stress but a 1/4″ plate is the minimum for other practical reasons and maintenance. The weight is only 12 lbs. per sq. foot or less than one inch thickness of concrete, so this floor is lighter than any other competitive floor in common use for sidewalks, today; even lighter than the common grating floors with mortar fills. The 1/4″ floor plate also serves as the top flange for the sidewalk crossbeams.

The sidewalk is designed to be made in 30′ sections by welding the fascia channel, the three longitudinal 2″ x 2″ x 3.56 lbs. tees at 24″ center and the 5″ x 4″ crossbeam tees at 6′—0″ centers to 97″ x 1/4″ x 30′ long section of multigrip checkered floor plate. Referring again to drawing, Fig. 1, these sections rest on the cantilever brackets. The plates notch around the vertical truss hangers and splice longitudinally to the 18″ x 3/8″ curb plate over the center line of the 2 1/2″ x 1 1/4″ channel with a continuous 1/4″ single V weld. All crossbeams splice to the sections attached to the vertical curb supports at the points adjacent to this same channel with 45° single V butt welds, as can be seen on drawing, Fig. 1.

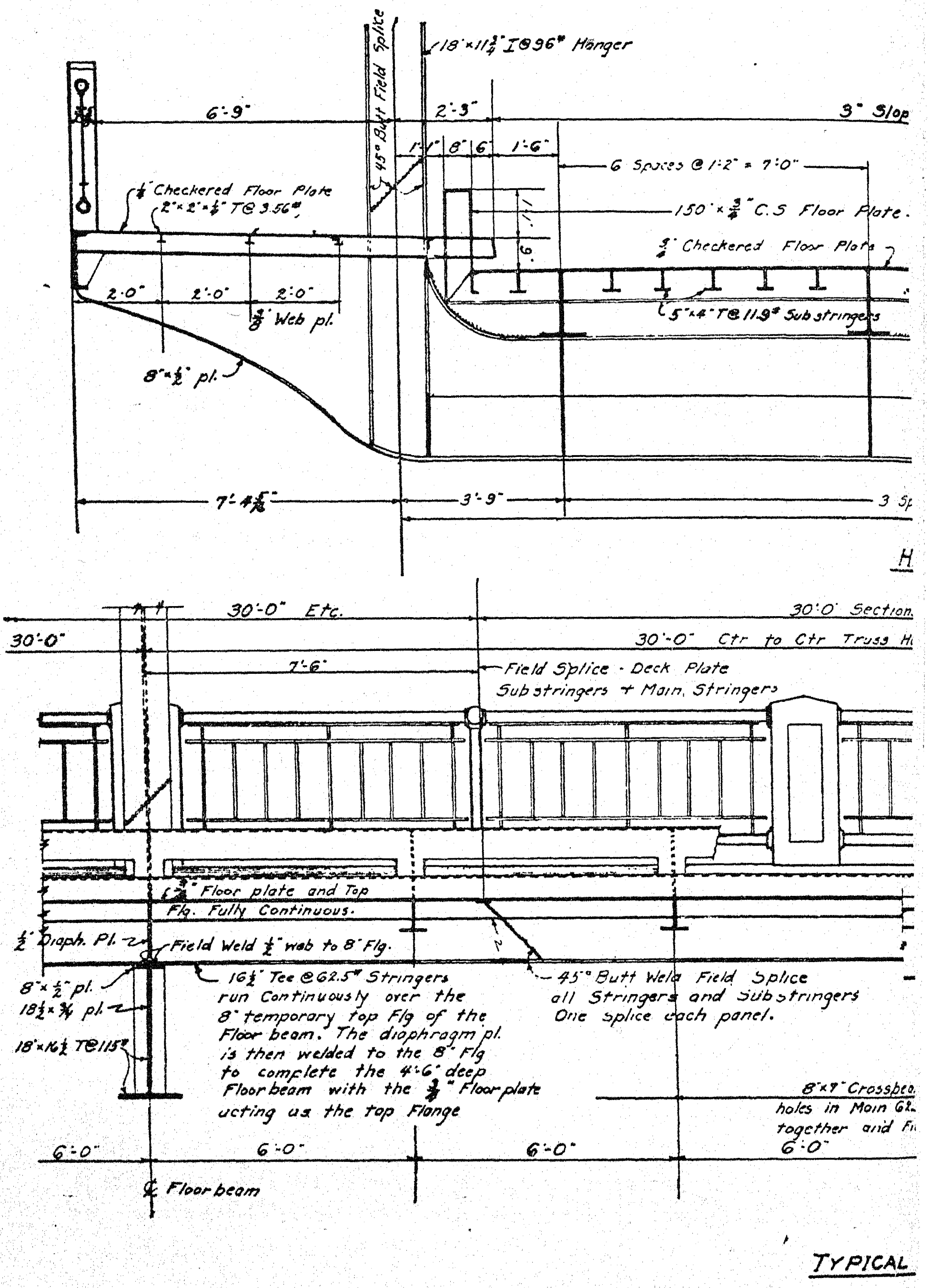
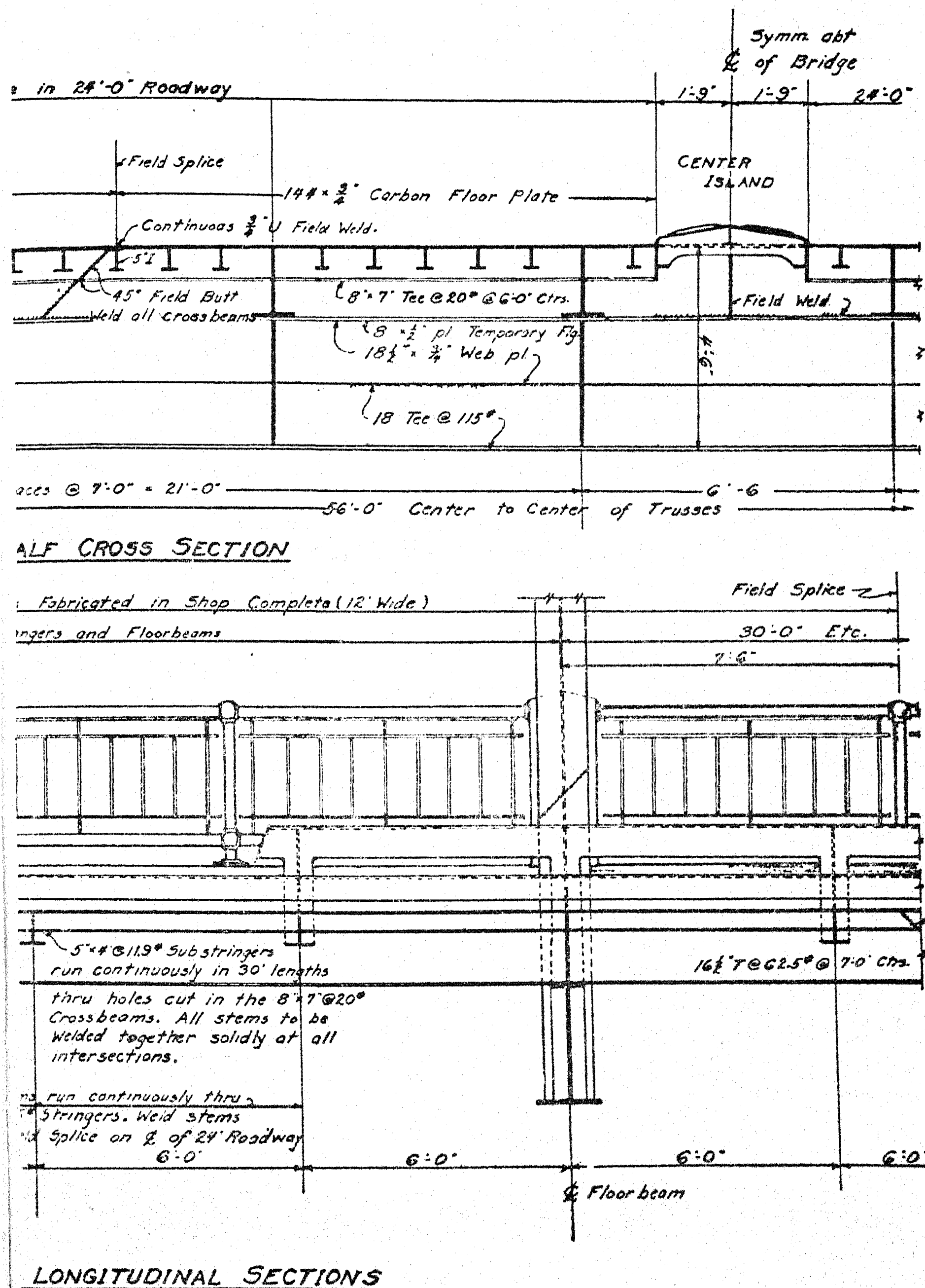


Fig. 2. Typical cross sectional and longitudinal section details of arc welded steel plate floor.


Symm. abt ℄ of Bridge
in 24'-0" Roadway
1'-9"
1'-9"
24'-0"
Field Splice
CENTER ISLAND
14# × 3/4" Carbon Floor Plate
Continuous 3/4" U Field Weld.
5" I
45° Field Butt Weld all cross beams
8" × 7" Tee @ 20# @ 6'-0" Ctrs.
Field Weld
8 × 1/2" pl. Temporary Flg.
18 1/2" × 3/4" Web pl.
18 Tee @ 115#
aces @ 7'-0" = 21'-0"
6'-6
56'-0" Center to Center of Trusses
ALF CROSS SECTION
Fabricated in Shop Complete (12' Wide)
ngers and Floorbeams
Field Splice
30'-0" Etc.
7'-6"
5" × 4" @ 11.9# Sub stringers run continuously in 30' lengths thru holes cut in the 8" × 7" @ 20# Crossbeams. All stems to be welded together solidly at all intersections.
16 1/2" T @ 62.5# @ 7'-0" Ctrs.
run continuously thru Stringers. Weld stems Splice on ℄ of 24' Roadway
6'-0"
6'-0"
6'-0"
6'-0"
℄ Floor beam
LONGITUDINAL SECTIONS

The Handrail.—The handrail indicated on drawings, Figs. 1 and 2, is made of 2½" or 3" wrought iron pipe with ¾" square verticals threaded through 2" x ⅜" flat horizontal bars. The framework is fabricated by electric arc welding and then welded to the pipe. The posts are welded box sections made from 5/16" plates. The sections of pipe railing are welded between the posts after adjusting the flanges to length and the center vertical pipe post is welded to the flooring.

An alternate, substantial and neat-looking wrought iron handrail can also be made entirely from large pipe, by using 9"ø posts at 15' centers, a 6"ø top rail 5"ø bottom rail and 3"ø verticals at 9" centers between the large posts. The posts should be capped with about ¾" spheres and the monotony interrupted by an occasional large concrete or stone post. Such a rail would be fabricated entirely by electric arc welding and would cost no more than for any other much less sturdy rail.

New Type of Sidewalk Framing.—The sidewalk is supported between the 15" fascia stringer and the outside roadway stringer near the curb. Usually an independent stringer is provided for the inside edge of the sidewalk located just outside the plane of the main truss web members. Such conventional arrangements require from 1½ to 2 times as much sidewalk floor system metal as does this arrangement. The outside roadway stringers support the sidewalks and curbs as well as the edges of the roadway and thus two complete rows of main stringers are saved. The additional load on the outside roadway stringer serves to give duplication with the other roadway stringers and this is economical, also.

The Center Island.—At the center of the bridge, the two twenty-four foot roadways are separated by a center island. This island is 3'—6" wide and is raised above the surfaces of the adjacent roadways 3" at the edge and 8" at the center. The edges are finished with 3" radius curved channel sections capable of spanning 6'—0" center to center of the crossbeams, which support the island. The top surface is made in a uniform pattern of ⅜" thick buckle plate with 16" square buckles and 2" flanges. The buckles are turned up and are made 3" deep. They span both transversely from the center rib to the edge channels and longitudinally between flanges at 18" centers and diaphragms at 6' centers.

This center island weighs only 96 lbs. per lin. ft. and is believed to be as entirely effective as any of the modern barriers existing on bridges in the East which weigh many times as much Modern barriers are all fabricated by the electric arc welding process because their shape does not lend itself readily to punching and riveting operations. Thus, the superiority of the process is proven and the economy is left to be or not to be, according to the ingenuity in the individual designer.

The Floor Plate Serves as Top Flange of the Floor Beams.—These floor beams span 56 feet center to center of truss hangers as shown on drawing, Fig. 2, and are spaced at 30′ centers, along the bridge or viaduct.

The total dead load is 3,356 lbs. per lin. foot of bridge.

The simple beam moments are calculated first and then corrected later for the negative moment in the hangers.

The dead load of the floor beam itself is only 200 lbs. per lin. ft. consisting of the section as shown on drawings, Figs. 1 and 3.

The live load is figured on the basis of ten-foot traffic lanes, 100% for two lanes, 90% for three lanes and 80% for the probability of having four lanes simultaneously at the position of maximum loading. 80% of four lanes governs with the wheels of the two center trucks two feet from the edge of the 3′—6″ center island.

The maximum live load moment is 52 times the reaction per line of truck wheels to the floor beam which in this case equals 18,130 lbs. for trucks spaced at 44′ centers.

The live load shear is maximum for 90% of three lanes when the two lanes are placed near the outside curb on the near roadway and the third lane adjacent to the center island on the far roadway. The maximum live load shear is thus calculated to be 3.5 times this same wheel load reaction.

The values for shear and positive moments are summarized on drawing, Fig. 3.

According to the Lehigh University tests on battledeck floors, as much as 48″ of a 3/8″ plate can be counted as floor beam flange. In this design a 48″ x 3/4″ plate is inserted under the center island between the two roadway surfaces for the purpose of serving as the top flange of the floor beam across this gap.

The Floor Beam Serves First in a Temporary Condition.—The moment of inertia of the floor beam is computed and the negative moment is determined by equating angular deflections in the hanger. The properties of this floor beam, both in its temporary condition with the 8″ x 1/2″ plate acting as the top flange and in its final condition with the floor plate acting as the top flange, are shown on drawing, Fig. 3. The full depth of section is completed by placing the sections of roadway stringers and decking on top of the temporary beam and welding the 1/2″ diaphragm plate to the top of the temporary 8″ x 1/2″ flange.

In the temporary condition the floor beam supports two thirds of

the final dead load while the 30-foot sections of floor are being connected to the cantilever section behind and set to cantilever 7′-6″ ahead, as shown on drawing, Fig. 1. The temporary beam must be cambered to deflect level in this condition. The hangers are 18″ x 12″ I beams @ 96 lbs. and have a maximum free length of 45 feet to the arch overhead, as shown on drawing, Fig. 4.

While in this condition the 16½″ x ½″ diaphragm plate is welded to the temporary flange plate, to complete the floor beam to its full depth for the remainder of the loads.

Hanger Connections.—The connection to the hanger is made by welding the ¾″ web plate solidly to the hanger section with a ¾″ shop weld and also by welding the flange plates solidly to the flanges of the 18″ hanger.

The cantilever brackets are made by arc welding 8″ x ½″ flange plates to a ⅜″ web plate as shown on drawing, Fig. 2. The stresses are nominal, the maximum shear is 10,000 lbs. and the maximum moment is 65,000′lbs.

The top flange is butt welded to the flange of the 18″ I beam hanger and a diaphragm plate is welded between the hanger flanges opposite the top flange of the cantilever bracket.

All hangers are field spliced just above the sidewalk floor plates with 45° butt welds of the same sizes as the metal to be spliced. On this angle the welds will be stressed only .7 the value of solid-metal.

This completes the entire design for the electric arc welded steel plate floor. As designed, this floor would make an excellent elevated viaduct to build over existing streets without interfering in any manner with the traffic beneath. The hangers would be replaced with rows of columns along the curbs where trolley poles and lamp poles are ordinarily located.

The Floor-system Is Also the Arch Tie.—Use is made of this same floor, as shown on drawing, Fig. 1, for the bottom chord of a tied arch truss. A medium span of 330 feet is shown on drawing, Fig. 4, the same span length as the new Passaic river lift bridge, selected for purposes of comparison. The reader will appreciate that any other multiple of 30-foot panels can be selected as the span length to fit any other particular situation. For very long spans, of course, more material may be required for the direct stresses in the floor-system, but for the 330-foot span selected, the maximum thrust of the arch is of little consequence outside of suitable details at the L_0 points.

Calculations for the arch ribs are given on drawing, Fig. 4. The maximum arch thrust is 1,400,000 lbs. per arch rib.

A tied arch rib, such as shown on drawing, Fig. 4, is better than an ordinary braced truss design at the same unit stress because the calculations for primary stress in the arch include all the factors representing both the secondary as well as the primary stress in the conventional braced truss design.

Stringer Contraction Joints Are Eliminated.—In most conventional trusses of this length of span, at least two stringer contraction joints

are provided to limit the accumulated cross-bending stresses in floor beams due to the live-load elongation of the truss chords and to limit the amount of stringer participation in chord stresses. Many ingenious devices have been invented to care for these overstresses such as flexible end connection angles on the stringers and cast steel expansion pockets, but the details in general are all unsatisfactory. These joints are completely eliminated in this new design. Due to the complete continuity afforded by the welded fabrication no such overstresses exist. The entire truss chord is eliminated and the elongation of the floor system at 3,300 lbs./sq." is negligible. It amounts to only $\frac{7}{16}$" in 330 feet. Stresses resulting therefrom and from rib-shortening in the arch can be eliminated by jacking before final closure of the arch. Temperature stresses do not exist, in the ordinary sense, because both the arch and the tie are free to adjust themselves to the same temperature changes.

Referring again to drawing, Fig. 4, attention is called to the design of the arch rib, to be completely fabricated by electric arc welding and the most important welds are nearly always in compression. All splices can be plain butt welded joints with full confidence and safety such as cannot be equally placed in conventional braced trusses where members are subjected to heavy tensile stresses and to great alternating conditions of stress.

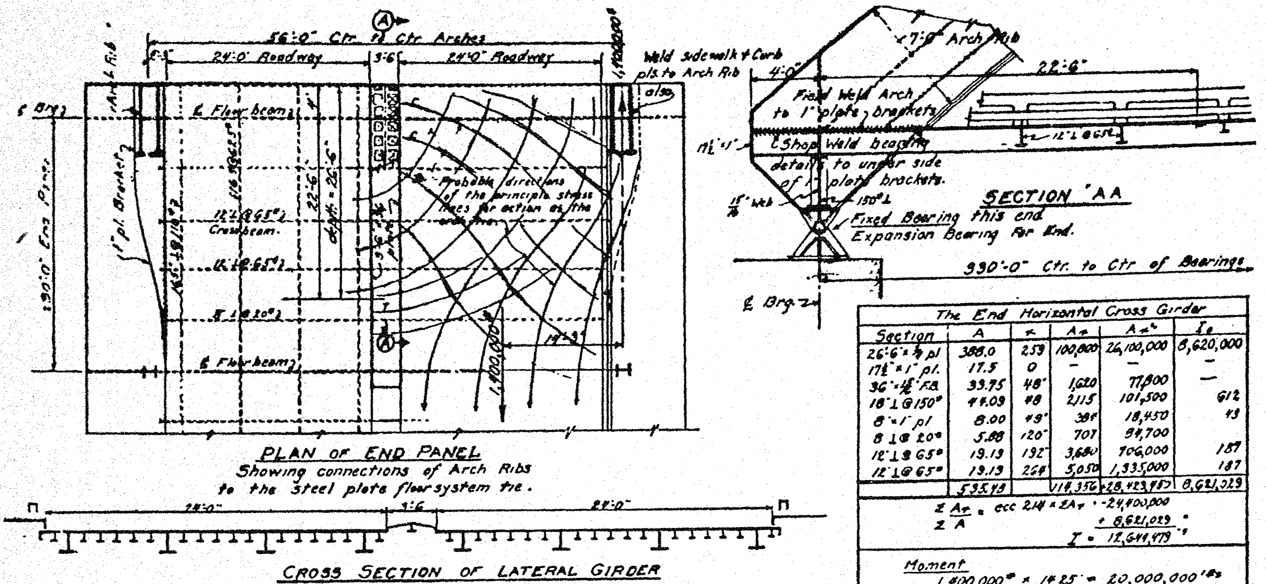
The Arch Ribs Are Lighter Than Ordinary Trusses.—For direct comparison, the arch rib tied by the floor-system has only seven sections of arch chord and ten vertical hangers, seventeen members in all and weighs only 915 lbs./lin. ft. of arch.

A similar Warren truss span for the Passaic river bridge has seven sections of top chord, eleven truss verticals, six sections of bottom chord and ten main diagonals or 34 members in all and it weighs 1,120 lbs./lin. ft. of truss. This bridge is of the same span and carries the same roadway with an open grating floor which is the lightest and most economical construction of the present.

The Warren truss has 13 major truss joints as compared to only 4 major field splices at L_0 and L_0' and 2 other points in the arch rib design.

The Floor Plate Provides the Horizontal Girder at Each End of Span:—The details for the connection of the floor-system to the arch rib at L_0 are suggested on drawing, Fig. 3. The essential elements of this connection are one-inch thick plate brackets welded to the edges of the $\frac{3}{4}$" floor plates, heavier outside roadway stringers, crossbeams and end floor beam. The strip between the two roadways is filled solid in the end panel by a $\frac{3}{4}$" by 3'-6" wide center plate. These elements complete a horizontal girder in the end panels with approximately 25 or 26 feet of effective depth and of far greater strength than required by the loads.

The Floor Plate Is the Bottom Lateral System.—This floor also serves as the bottom lateral system. On drawing, Fig. 3, a calculation is shown for the moment of inertia and section modulus of the roadway section for resistance against lateral stresses. The moment of inertia



The End Horizontal Cross Girder

Section	A	x	Ax	Ax²	Io
26'6"×½ pl	388.0	259	100,800	26,100,000	8,620,000
17½"×1" pl.	17.5	0	—	—	—
36"×½" F.B.	33.75	48"	1,620	77,800	—
18" ⊥ @ 150#	44.09	48	2,115	101,500	612
8"×1" pl	8.00	49"	394	18,450	43
8 ⊥ @ 20#	5.88	120"	707	84,700	
12" ⊥ @ 65#	19.13	192"	3,680	706,000	187
12" ⊥ @ 65#	19.13	264	5,050	1,335,000	187
	535.49		114,356	28,423,987	8,621,029

$\frac{\Sigma Ax}{\Sigma A}$ = ecc 214 × ΣAx = −24,400,000

+8,621,029

I = 12,644,479

Moment

1,400,000# × 14.25' = 20,000,000'#

Stress

$f_b = \frac{20,000,000 \times 12 \times 304"}{12,644,000} = +5800 \#/" \ T.$

or × 214" = −4070 #/" C

Moment of Inertia (One Roadway)

Section	A	x	Ax	Ax²	Io
44×¾ pl.	38.00	72	2,780	560,000	186,624
5" ⊥ @ 11.9#	3.49	14	49	685	2
"	3.49	28	98	2,740	2
10½ ⊥ @ 62.5#	18.39	42	773	32,500	94
5" ⊥ @ 11.9	3.49	56	195	10,900	2
"	3.49	70	244	17,100	2
"	3.49	84	293	24,600	2
"	3.49	98	342	33,500	2
"	3.49	112	392	44,000	2
10½ ⊥ @ 62.5	18.39	126	2,320	293,000	94
5 ⊥ @ 11.9	3.49	140	489	68,500	2
	172.70			1,087,525	186,839

186,839

One half of one roadway = 1,274,364

Other Half 1,274,364

Total 2,548,728 "⁴

Moment of Inertia

Both Roadways Combined

A_x 345.4" × 165" = 9,420,000

$-{}^{1}\!/\!_{2}\,I_o$ = 2,548,000

One Rdwy abt ℄ = 11,968,000

11,968,000

Total 23,936,000"⁴

Wind Moment

$M = \frac{470\# \times 330^2}{8} = 6,400,000'\#$

Stress

$f_b = \frac{6,400,000 \times 12 \times 312"}{23,936,000} = 1000 \#/"$

Wind Areas

Handrail	.5 sq ft.
Fascia	1.5
Upper Curb	.58
Lower "	.50
Floor	1.50
½ Hangers	.42
	6.00 sq ft
50% for side	3.00
Total	9.00

9 × 30# = 270 #/lin'

Live load − 200

470 #/l.ft

or

9 × 50# = 450 #/l.f.

Summary of Floor Plate Stresses

Direction	X	Y
As Flooring	*±9,800 #/"	0
As Substringer Flg.	0	±4,600 #/"
As Crossbeam Flg.	* 4,160 #/"	0
As Stringer Flg.	0	±3,150 #/"
As Floorbeam Flg.	* 9,000 #/"	0
As Arch Tie	0	+3,300 #/"
As Lateral Girder		±1,000 #/"
Possible Total.	18,800 #/"	+18,050 #/"
Probable Max	14,000 #/"	−10,450 #/"

* Not Simultaneous

$R = \sqrt{14,000^2 + 10,450^2} = 17,500 \#/"$

Fig. 3. Properties of sections computed. See also page 553b.

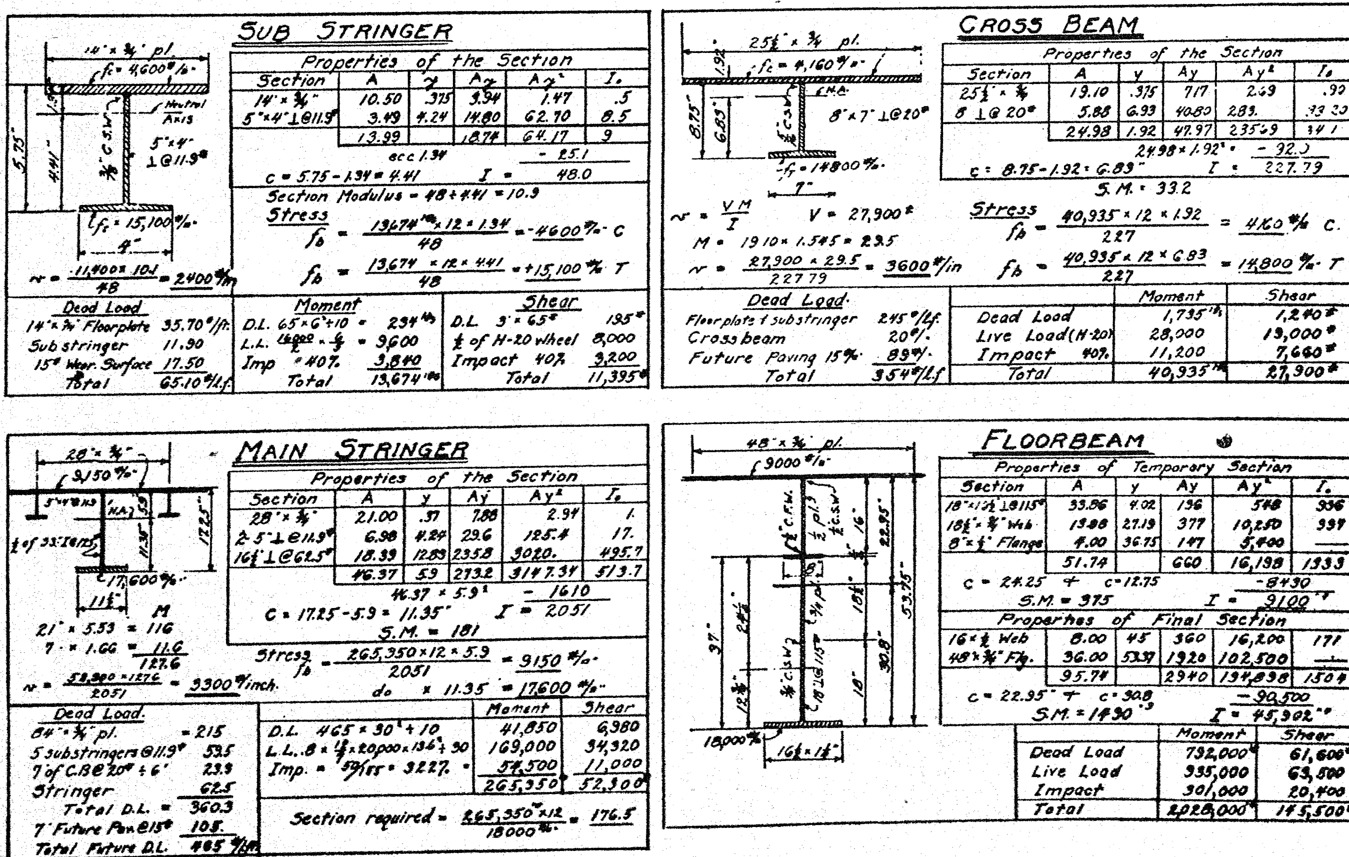


Fig. 3. Properties of sections computed. See also page 553a.

of a single 24-foot roadway is given as 2,548,000″⁴. Two of these individual roadway units are connected together by the center island into one horizontal girder 52 feet wide between curbs and together, the two roadways give a combined moment of inertia of 23,930,000″⁴. In addition to this great strength as a horizontal girder, we have two more girders each nine feet deep in the sidewalks which are neglected in this calculation.

This great girder has only to resist the lateral wind loads against the floor-system itself and whatever live load may be present on the bridge at the same time. The floor-system is shallow and there are no bottom truss chords or lateral system to be exposed to the wind so these loads are less than for any other conventional bridge. Neither are there any diagonal web members in the truss.

Conventional Single Plane Bottom Laterals Have Many Faults.—Economically this represents a saving of approximately 45,000 lbs. of structural metal, worth about $2,500.00, for the span shown on drawing, Fig. 4, as compared to a conventional Warren truss bridge.

Five Struts Constitute the Entire Top Lateral System.—The electric arc welded plate girder arches, shown on drawing, Fig. 4, also have other advantages over conventional practice. The arch ribs are made wide and massive so that the bracing points can be placed over sixty feet apart. For the top lateral bracing, five transverse struts are shown on drawing, Fig. 4 and they, with moment carrying end connections to the arch ribs, constitute the entire top lateral system. This lateral system is designed as a vierendeel girder and has to resist only the top chord wind.

Conventional Bracing Systems Are Composed of Many Members.—Conventional top lateral bracing systems are also designed for nominal stresses but they are composed of many members and the metal is grossly inefficient. The loads on conventional bracing systems consists of top chord wind and top chord participation stresses. The wind stresses are always nominal and the participation stresses are usually larger than the wind stresses. The participation stresses tend to make the top lateral slack as the chords shorten under stress and these stresses require that the top laterals be designed as stiff members in order to be effective. The participation stresses are equivalent to those caused by a lateral shear of 2½% of the sum of the chord stresses. They are maximum at the center line of span where normally the wind stresses are small.

These stresses are entirely eliminated in the arch design because the diagonal members of a conventional top lateral system are also entirely eliminated. In magnitude 2½% of the arch rib thrusts represents 65,000 pounds shear that the vierendeel system does not have to resist and yet the struts will be recognized as conventional bracing practice in deck bridge construction for concrete arch ribs.

For comparison, the top lateral bracing, sway frames, portals and struts have been estimated for a conventional 330-foot span through Warren Truss bridge of equivalent width. The members are all proportioned for an l/r not greater than 140, according to standard

specification. The weight of this top bracing for the 330′ span Warren Truss consists of:

	Lbs.
20 top lateral diagonals	90,000
5 top struts	28,000
5 sway frames	69,000
2 portals	40,000
Total lbs.	227,000

This comparison indicates a saving of 137,000 pounds of expensive metal in favor of the arch design which in turn is made possible by using this arc welded steel plate floor system as the arch tie. Additional advantages accrue in favor of the arch struts of welded designs, in the unit price costs, because the metal is concentrated in only five large strut members as compared to the 32 members listed above for the conventional bridge made up of literally thousands of lacing bars and other small parts.

Arc Welded Floor Is 17% Lighter.—For purposes of comparison the following detailed summary of bridge weights is submitted. The first column is for a conventional through Warren Truss of economical design carrying a 21 lb./sq.′ open grating floor. The second column is for the bridge of drawing, Fig. 4, with this new arc welded steel plate floor.

	Warren Truss Open Grating Floor 5/16" Bars	Tied Arch ¾" Arc Welded Plate Floor
	Lbs.	Lbs.
Floor-system, Handrails and Curbs	933,000	1,273,000
Floor Grating	420,000	....
Bottom Laterals	45,000	....
Top Laterals and Bracing	227,000	90,000
Two Trusses	780,000	604,000
Additional Metal in end panel	....	30,000
Total Weight of Bridge, lbs.	2,405,000	1,997,000

This difference of 408,000 pounds in the weight of the superstructure metal represents a total saving of 17% in weight. The figure given is accurate because this Warren truss bridge has been completely designed and is to be used as a lift span. The detailed computations were all made by the writer and are available but are omitted here for the sake of brevity.

The Arc Welded Floor Creates a New Standard of Economy.—Returning now to the new arc welded steel plate floor, as shown on drawings, Figs. 1 to 4, it is evident that the additional savings in stringers, floorbeams, trusses and lateral systems will be sufficient to

change this entire picture of economy because the floor also possesses the advantage of being light-weight.

These additional savings total 408,000 pounds of superstructure metal in favor of the new arc welded design when compared on the basis of a simple span. This metal is estimated to be worth 6c a pound and represents at least $24,480 in cost. This figure divided by 336 feet is $72.85 per linear foot of bridge cheaper than the open-grate type. This saving is for a simple fixed span and does not reflect any of the savings that also accrue in unit costs and in the substructure. The detailed breakdown of unit costs into material and labor operations follows, but first we will briefly touch on the value of this saving in weight in the consideration of a movable span such as a lift span.

One Pound Load on a Lift Span Costs Six Cents.—For a 1,500,000 pound load to lift the cost in cents for each pound of difference in weight of the fixed span is given in detail as follows:

Tower and Span Metal	.327 lb. @ 5.5¢ x .75 =	1.35¢
Counterweights	1.153 lb. @ 1.0¢ x .75 =	.87¢
Tower sheaves, shafts & bearings	.111 lb. @ 15.0¢ x .75 =	1.25¢
Ropes	.044 lb. @ 20.0¢ x .75 =	.66¢
Balance Chains	.052 lb. @ 8.0¢ x .75 =	.31¢
Operating Machinery	.028 lb. @ 20.0¢ x .75 =	.42¢
Motors, Engine, House, etc.		1.00¢
Total savings per pound of load		5.86¢

The corresponding figures for other loads to lift are:

2,000,000 lb. load to lift one pound	6.20¢
2,500,000 lb. load to lift one pound	6.60¢

Therefore if our 330-foot arch span, with this new arc welded steel plate floor were to be converted into a lift span similar to the ordinary Warren truss lift span with the open-grating floor, the saving of 408,000 pounds of superstructure metal is worth an additional $25,296.00 saving in cost in the towers and machinery due to the reduction in the load to lift when figured at 6.2c per pound. Large gross savings would accrue to industry through the general adoption of this design.

SUMMARY OF COSTS FOR A TYPICAL 30 FT. PANEL OF FLOOR-SYSTEM

Weight..........111,340 lbs.

Material	$2,888.00	$52.00 per ton	2.600¢ per lb.
Cutting	60.18	1.08 per ton	.054¢ per lb.
Welding	875.65	15.75 per ton	.788¢ per lb.
Shipping	278.00	5.00 per ton	.250¢ per lb.
Erection and Handling	361.00	6.50 per ton	.325¢ per lb.
Cleaning and Painting	139.00	2.50 per ton	.125¢ per lb.
Total costs	$4,601.83	$82.83 per ton	4.142¢ per lb.

Divided by 30 ft. this equals	$153.00 per lin. ft.
Two wrought iron handrails	9.00 per lin. ft.
Total cost per lin. ft.	$162.00

The equivalent width of bridge roadway

Two roadways @ 24 feet each	48.0 ft.
One center island	3.5 ft.
One-half of two 10 foot sidewalks	10.0 ft.
Total	61.5 ft.

$162.00 per ft. divided by 61.5 sq. ft. equals $2.64 per sq. ft.

This cost of $2.64 per square foot represents the total cost of the floor-system, curbs and handrails, including the stringers and floor-beams for a bridge consisting of a continuous series of thirty-foot spans.

For comparison with standard viaduct or elevated highway construction, the substructure costs must also be included.

For estimating the costs, the unit prices paid to the successful bidder for similar construction will be used taken from the Grand Avenue Viaduct at Sioux City, Iowa. This viaduct is of recent construction (1936-37) and is most modern in design.

Cost for Two Concrete Pedestals and Columns

Item	Quantity			Concrete Piles	Timber Piles
Concrete	31 c. y.	@	$19.00	$ 590.00	$590.00
Reinforcement	3,100 lbs.	@	.038	118.00	118.00
8 Concrete Piles	240 l. f.	@	2.00	480.00	---------
10 Creo. Tim. Piles	300 l. f.	@	.80	---------	240.00
Total				$1,188.00	$948.00
Divided thirty feet equals				$ 39.60	$ 31.60
The superstructure costs				162.00	162.00
Total cost per linear foot of viaduct				$201.60	$193.60
Divided by 61.5 equals cost per sq. ft.				$ 3.27	$ 3.15

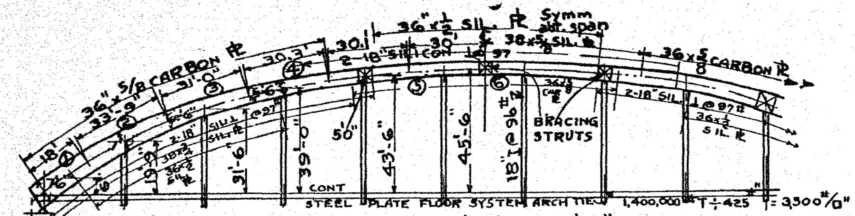
Ordinary viaducts cost as high as $5.00 per sq. ft. and often more. That is why the comparison is made to Grand Ave. Viaduct. It was of most economical proportions and cost only $4.18 per sq. ft.

The ratio of costs for the viaduct with the arc welded steel plate floor, as compared to the conventional, is as $3.15 is to $4.18 or only 75% as much. Thus, the welded design shows up very favorably because the flooring has been utilized for the many other purposes listed on drawing, Fig. 3, even though when compared on the basis of flooring alone, it might be much more expensive.

Summary of Cost for 1,080 lin. ft. of Viaduct
Substructure (16 bents)

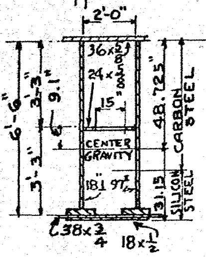
Item	Quantity		Unit Cost	Total Cost
1—Excavation	1,574 c. y.	@	$ 1.00	$ 1,574.00
2—Concrete Footings	560.7 c. y.	@	19.00	10,653.00
3—Beams and Columns	604.7 yds.	@	19.00	11,489.00
4—Reinforcement	139,660 lbs.	@	.038	5,307.00
5—Creosoted Timber Piles (30")	15,600 l. f.	@	.80	12,480.00
Total Cost of Substructure				$ 41,503.00

Divided by 1,080 lin. ft. = $38.40 per lin. ft. or $2,590.00 per bent.



11 PANELS @ 30'-0" = 330'-0" SPAN

TYPICAL TIED PLATE GIRDER ARCH

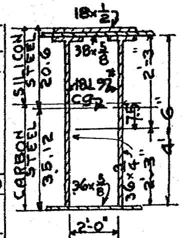


SECTION @ ③					
SECTION	A	y	Ay	Ay²	Io
60x3/4 ℞	45.00	+9"	+405	3,650	13,500
60x3/4 ℞	45.00	+9	+405	3,650	13,500
24x5/8 ℞	15.00	0	—	—	—
36x5/8 ℞	22.50	+39.31	+886	34,800	—
18"⊥@97#	28.56	-34.2	-976	33,300	904
18⊥@97#	28.56	-34.2	-976	33,300	904
38x3/4	28.50	-39.37	-1120	44,200	—
36x1/2	18.00	-40.00	720	28,800	—
A = 231.12			-2096	181,700	28,808
	ecc -9.1			-19000	
				I = 191,508"#	

SECTION @ ⑥					
SECTION	A	y	Ay	Ay²	Io
2-36x3/4 ℞	54.00	-9.00	-486	4,380	5,832
1-36x5/8 ℞	22.50	-27.31	-615	16,800	—
2-18"⊥@97#	57.00	+22.2	+1266	28,200	1,808
1-38x5/8 ℞	23.75	+27.31	+650	17,700	—
2-18x1/2 ℞	18.00	+27.86	+500	13,950	—
A	175.25		+1315	81,030	7,640
	ecc = +7.50"			-9,870	
			I =	78,800"#	

SECTION	A	r	Ar	Ar²	Io
2-36x3/4 ℞	54.00	±12.37	—	8.250	—
1-36x5/8 ℞	22.50	0	—	—	2430
2-18"⊥@97	57.00	±12.37	—	8,720	355
1-38x5/8 ℞	23.75	0	—	—	2858
2-18x1/2 ℞	18.00	± 9.5		1,625	485
	175.25			18,595	6,128

$r = \sqrt{\dfrac{24713}{175.25}} = 11.9"$ $\quad I = \dfrac{6{,}128}{24{,}713}$



fc: SILICON STEEL $20{,}000 - .46\left(\frac{\ell}{r}\right)^2$

$\frac{\ell}{r} = \frac{740}{11.9} = 62 \quad fc = 18230\#/\square"$

fc: CARBON STEEL $15{,}000 - .25\left(\frac{\ell}{r}\right)^2 = 14{,}040\#/\square"$

$$H = \frac{\int My \frac{ds}{I}}{\int y^2 \frac{ds}{I}} \qquad \frac{ds}{I} = \infty \qquad \int x^2 \frac{ds}{I} = \infty$$

	GIVEN					COMPUTED		DEAD LOAD			
DIV. NO	LGTHS ds	d	I	ds/I	y	∫y ds/I	∫y² ds/I	Ms	Msy ds/I	HY	M
1	18.0	7'-1½"	11.0	1.63	6.0	9.82	59	+3,500'K	34,400	-5,110	-1,610,000
2	33.75	7'-0"	11.0	3.07	19.25	59.	1,137	+13,640	805,000	-16,400	-2,760,000
3	31.0	6'-6"	9.24	3.36	30.75	103.	3.170	+24,517	2,530,000	-26,200	-1,683,000
4	30.3	5'-6"	6.00	5.05	38.5	194.	7.500	+32,433	6,280,000	-32,800	-367,000
5	30.1	5'-0"	5.85	5.15	43.5	224.	9,750	+37,805	8,470,000	-37,100	+705,000
6	30.0	4'-6"	3.70	8.10	46.08	374.	17,200	+40,378	15,050,000	-39,230	+1,148,000

$H_{for\ \Delta 1"} = \dfrac{4{,}320{,}000{,}000 \times .083}{77{,}632} = 4630\#$

LEFT HALF = 38,816
RIGHT " = 38,816
$\int y = \frac{ds}{I}$ $\quad I_y = 77{,}632$

$H = \dfrac{33{,}169{,}400}{38{,}816} = 853{,}000\#$

$V = 466{,}370\#$

DEAD LOAD						
LOAD	L1	2	3	4	5	6
ARCH RIB	16,000	27,500	25,000	22,500	19,500	17,500
VERTICALS	0	2,200	3,300	3,900	4,400	4,570
DETAILS	10,000	500	500	500	500	500
STRUTS	5,000		12,000		11,000	5,000
FLOORMETAL	37,000	57,900	57,900	57,900	57,900	57,900
TOTAL	68,000	88,100	98,700	84,800	93,300	85,470
DEAD LOAD REACTION 518,370#						

Fig. 4. Typical tied plate girder arch and calculations for the arch ribs. See also page 557b.

DIV. NO.	GIVEN y	GIVEN $y\frac{ds}{I}$	UNIT LOAD@2 Ms	UNIT LOAD@2 $M_sy\frac{ds}{I}$	UNIT LOAD@2 Hy	UNIT LOAD@2 M	UNIT LOAD@3 Ms	UNIT LOAD@3 $M_s\frac{ds}{I}$	UNIT LOAD@3 Hy	UNIT LOAD@3 M
1	6.	9.82	6.80	66.5	-2.22		6.15	60.3	4.26	+1.89
2	19.25	59.00	27.30	1,610	-7.13	+20.17	24.6	1450	-13.65	+10.95
3	30.75	103.00	24.60	2,540	-11.38	+13.22	49.2	5080	-21.80	+27.40
4	38.50	194.	21.84	4,240	-14.25	+7.59	43.2	8380	-27.30	+15.90
5	43.50	224.	19.1	4,280	-16.10	+3.0	37.8	8480	-30.90	+6.9
6	46.08	374.	16.39	6,130	-17.05	-.66	32.4	12,120	-32.70	-.3
6	46.08	374.	13.65	5,100	-17.05	-3.40	27.0	10,100	-32.70	-5.7
5	43.50	224.	10.9	2,440	-16.10	-5.20	21.6	4,850	-30.90	-9.3
4	38.50	194.	8.2	1,590	-14.25	-6.05	16.2	3,140	-27.30	-11.1
3	30.75	103.	5.46	563	-11.38	-5.92	10.8	1,110	-21.80	-11.0
2	19.25	59.	2.73	161	-7.13	-4.40	5.4	319	-13.65	-8.25
1	6.	9.82	.68	6.68	2.22		1.35	13.3		
			$H = \frac{28,727.18}{77,632} = .37$				$H. = \frac{55,102.6}{77,632} = .71$			
			RL = .91		RR = .09		RL = .82		RR = .18	

DIV. NO.	UNIT LOAD@4 Ms	UNIT LOAD@4 $M_s\frac{ds}{I}$	UNIT LOAD@4 Hy	UNIT LOAD@4 M	UNIT LOAD@5 Ms	UNIT LOAD@5 $M_s\frac{ds}{I}$	UNIT LOAD@5 Hy	UNIT LOAD@5 M	UNIT LOAD@6 Ms	UNIT LOAD@6 $M_s\frac{ds}{I}$	UNIT LOAD@6 Hy	UNIT LOAD@6 M
1	5.46	53.6			4.76	46.7			4.08	40.1		
2	21.85	1290	-19.6	+2.25	19.10	1,130.0	-24.1	-5.0	16.35	965	-26.9	-10.55
3	43.70	4510	-31.4	+12.30	38.20	3,940.	-38.5	-.3	32.70	3370	-43.0	-10.30
4	65.50	12,700	-39.3	+26.20	57.3	11,150	-48.1	+9.2	49.00	9500	-53.9	-4.9
5	57.20	12,800	-44.3	+12.9	76.3	17,100	-54.3	+22.0	65.40	14,650	-60.9	+4.5
6	49.0	18,350	-47.0	+2.0	65.5	24,500	-57.6	+7.9	81.8	30,600	-64.5	+17.3
6	40.8	15,300	-47.0	-6.2	54.6	20,500	-57.6	-3.0	68.3	25,600	-64.5	+3.8
5	32.7	7,340	-44.3	-11.6	43.7	9,800	-54.3	-10.6	54.5	12,200	-60.9	-6.4
4	24.5	4,750	-39.3	-14.8	32.8	6360	-48.1	-15.3	41.0	7,950	-53.9	-12.9
3	16.35	1,685	-31.4	-15.05	21.8	2245	-38.5	-16.7	27.3	2,810	-43.0	-15.7
2	8.18	483	-19.6	-11.42	10.9	643	-24.1	-13.2	19.6	803	-26.9	-13.3
1	2.04	20			2.75	27.0			3.42	33.6		
	$H = \frac{79,281.6}{77,632} = 1.02$				$H = \frac{97,441.7}{77,632} = 1.25$				$H = \frac{108,521.7}{77,632} = 1.40$			
	RL = .728		RR = .272		RL = .636		RR = .364		RL = .545		RR = .455	

INFLUENCE LINE ORDINATES

LOAD	2	3	4	5	6	H
2	+20.17	+13.22	+7.59	+3.0	-.66	.37
3	+10.95	+27.40	+15.90	+6.9	-.30	.71
4	+2.25	+12.30	+26.20	+12.9	+2.00	1.02
5	-5.00	-.30	+9.20	+22.0	+7.90	1.25
6	-10.55	-10.30	-4.90	+4.5	+17.3	1.40
6	-13.30	-15.70	-12.90	-6.4	+3.8	1.40
5	-13.20	-16.70	-15.30	-10.6	-3.0	1.25
4	-11.42	-15.05	-14.80	-11.6	-6.2	1.02
3	-8.25	-11.00	-11.10	-9.3	-5.7	.71
2	-4.40	-5.92	-6.05	-5.2	-3.40	.37
MAX POS.	+33.37	+52.92	+58.89	+49.3	+31.00	
MAX NEG.	-66.12	-74.97	-65.05	-43.1	-19.26	
WHOLE SPAN	-32.75	-22.05	-6.16	+6.2	+11.74	9.50

MAXIMUM POSITIVE MOMENTS

LOAD	2	3	4	5	6	R₁ LEFT	THRUST
DEAD LOAD	-2,760,000	-1,683,000	-367,000	+705,000	+1,148,000	466,370	853,000
15# FUTURE PAV.				+67,000	+127,000	59,000	102,500
SIDE WALK 62.5#/□'	+400,000	636,000	707,000	+593,000	+372,000	49,000	57,000
UNIFORM H20	+1,120,000	+1,780,000	+1,980,000	+1,655,000	+1,040,000	137,000	192,000
CONC. H20	+637,000	+867,000	+827,000	+695,000	+546,000	23,000	44,200
IMPACT	+385,000	+585,000	+560,000	+394,000	+270,000	34,000	52,000
TOTAL	-218,000	+2,185,000	+3,707,000	+4,109,000	+3,503,000	768,370	1,300,700#

MAXIMUM NEGATIVE MOMENTS

LOAD	2	3	4	5	6	R₁ LEFT	THRUST
DEAD LOAD	-2,760,000	-1,683,000	-367,000	+705,000	+1,148,000	466,370	853,000
15# FUTURE PAV.	-354,000	-238,000	-66,700			59,000	102,500
SIDE WALK 62.5#/□'	-796,000	-900,000	-782,000	-517,000	-231,000	39,300	89,000
UNIFORM H20	-2,230,000	-2,520,000	-2,190,000	1,450,000	-650,000	110,000	249,000
CONC. H20	-420,000	-527,000	-483,000	-366,000	-196,000	11,500	39,560
IMPACT	-398,000	-457,000	-480,000	-306,000	-100,000	18,130	52,000
TOTAL	-6,958,000	-6,325,000	-4,368,700	1,934,000	-29,000	704,300	1,385,000

DEAD LOAD

ARCH RIB & HANGERS

26,000	@ L1
30,200	2
28,800	3
26,900	4
24,400	5
22,570	6
158,870#	
× 2	
317,740#	FOR

ONE COMPLETE RIB ÷ 336' = 945#/LIN.FT.
INCLUDING SPECIAL STRUT AND DETAILS @ L1

H-20 LIVE LOAD

640#/LIN.FT. OF EACH 10 FT. TRAFFIC LANE
18,000# CONC. LOAD " " " "
90% FOR 3 LANES LOADED = 1.75 LANES
PER ARCH × 640 = 1120#/LIN.FT.
1120 × 30' = 33,600 LB.
18,000 × 1.75 = 31,500 L'

$$I = \frac{50}{125 \times L}$$

STRESS @ 3

$$fd = \frac{1,385,000}{231} = 5,900\ \#/\square''\ \text{DIRECT}$$

$$fb = \frac{6,325,000 \times 12 \times 31.15}{191,500} = -12,350\ \#/\square''\ \text{BENDING}$$
$$-18,250\ \#/\square''\ \text{COMPRESSION}$$

$$fb = \frac{6,325,000 \times 12 \times 48.72}{191,500} = +19,300\ \#/\square''$$
$$+13,400\ \#/\square''\ \text{TENSION}$$

STRESS @ 6

$$fd = \frac{1,300,700}{175} = -7450\ \#/\square''$$

$$fb = \frac{3,503,000 \times 12 \times 20.6}{78,800} = -11,000\ \#/\square''$$
$$= -18,450\ \#/\square''\ C$$

$$fb = \frac{3,503,000 \times 12 \times 35.12}{78,800} = +18,800$$
$$+11,350\ \#/\square''\ T$$

Fig. 4. Calculations for the arch ribs. See also page 557a.

Superstructure (16 spans)

6—Concrete in Slabs	1,340	c. yds.	@	$17.00	$ 22,800.00
7—Reinforcement Steel	101,120	lbs.	@	.038	3,840.00
8—Welded Reinforcing Trusses	261,400	lbs.	@	.039	10,200.00
9—Structural Steel (Riveted)	1,276,170	lbs.	@	.053	67,700.00
10—Handrail and Curbs (Welded)	217,749	lbs.	@	.07	15,200.00
11—Blast Plates (W. I.)	4,408	lbs.	@	.10	440.00
12—Cast Steel	34,824	lbs.	@	.15	5,230.00
13—Cast Iron	3,300	lbs.	@	.10	330.00

Total Cost of Superstructure $125,740.00
Divided by 1,080 lin. ft. = $116.00 per lin. ft.
Total Cost .... $154.40 per lin. ft. of viaduct.

The equivalent roadway width of Grand Ave. Viaduct is:
One roadway .... 32 ft.
½ of two sidewalks .... 5 ft.
37 ft.

$154.40 ÷ 37 ft. = $4.18 per sq. ft.

The equivalent cost of the electric arc welded steel plate floor viaduct is $\frac{37}{61.5}$ x \$195.30 = \$117.50 per foot of viaduct for the same roadway width, or the conventional concrete and steel viaduct to carry two 24-foot roadways will cost $\frac{61.5}{37}$ x \$154.40 = \$256.64 per lin. ft. of viaduct as compared to only \$195.30 for the electric arc welded steel floor viaduct presented by this paper. These ratios represent a 25% saving for the welded steel viaduct on concrete piles as compared to the conventional viaduct on wooden piles.

The economy at first appears to be all in the substructure and emphasizes the importance of the saving in dead load weight but it is to be remembered that the superstructure of the steel plate floor includes the floor beam, whereas, the transfer girder in this typical viaduct is in the substructure cap on the concrete bent.

All previous figures have been based on a typical 30-foot panel more or less selected at random and not necessarily economical. A panel twice as long, a 60-foot panel, is now selected for comparison because the results bring out some additional interesting advantages possessed by this new type of electric arc welded steel plate floor.

By adding 17″ x 9/16″ web plates to each 62.5 lbs. T section and deepening the stringer from 16½″ to 33″, a tee section is obtained that weighs only 100 lbs. per foot, does not require web stiffeners and furnishes the required section modulus of 460 by acting in conjunction with the floor plate as top flange. The stresses in the floor plate are practically unchanged and the span can be doubled by adding only 37.5 pounds of web metal per foot of stringer.

The corresponding increase in depth of floorbeam increases the floorbeam depth to 6′-0″ and furnishes the required floorbeam strength with but slight modifications. Economically, there are only one half as many floorbeams and only one half as many transverse field splices in the floor system for any given length of bridge.

The span length can be doubled and the total cost per linear foot of viaduct actually decreases. This indicates great flexibility in design

such as present day bridge structures completely lack. By using this new floor, in future bridge truss structures, much longer panels can be used in the floor system without extra load penalties, subdivision of truss panels will be made uneconomical rather than economical, truss weights will be reduced by omitting posts, hangers and sub-posts from the trusses themselves and sweeping architectural advantages will be gained.

This also indicates that for any given length a great change in live load can be taken into account in the design with but little effect on the cost for structures similar to that shown on drawing, Fig. 1. This fact is quite contrary to the expectation of our conventional economic curves of bridge costs. The writer recently designed a similar bridge, of riveted construction, for heavy railroad loadings which also bears out this conclusion. The railroad bridge is a double track three span continuous deck girder bridge of very shallow construction on 80-foot spans. Five girders were used per track with a ¾" thick steel plate floor.

The design revealed that a change from E-72 loading to E-80 made no increase in the cost of the superstructure and also that the exceedingly shallow depth of girder of 53 inches for an 80 ft. span was no penalty on the economic cost. In fact the depth could have been reduced to 50 inches at a slight saving in cost. The comparison also indicated that a change in live road to E-90 would not change the total cost of superstructure over 2%.

These features possessed by this new electric arc welded steel plate floor, in addition to the natural economies of arc welding, as compared to riveting, are of great economic advantage in the industry. Time will eventually prove this and it is the hope of the writer that this paper may be of some slight aid in accelerating the process.

This same floor system, as shown on drawing, Fig. 1, can also be used as the arch tie for the arch truss shown on drawing, Fig. 4. The economy claimed for a viaduct with this arc welded floor is 25% of the cost of the conventional standard concrete floor viaduct.

Arc Welding Is a Superior Method of Fabrication.—The design used herein for illustrative purposes is ultra conservative. The welds are all figured on 45° for 1.4 times the section and none are of minimum section. The costs can be materially reduced still further by more scientific methods of design already known to the author and by a still more general application of the science of electric arc welding. About 50% of the savings are due entirely to electric arc welding as a superior method of fabrication when compared to rivetting. The remainder of the saving is due to designing for welding so as to convert ordinary uneconomic floor metal to efficient metal by utilizing it for these many more useful purposes.

This general economy of the electric arc welded steel plate floor, in both the substructure and superstructure, when compared to the conventional simple span bridge or viaduct, indicates a great possible social advantage. Millions of dollars worth of our natural iron and steel resources, can be conserved annually by merely adopting the natural advantages of electric arc welding, as pointed out in this paper.

Literally thousands of bridges are constructed every year in the United States and in all other parts of the world.

The Arc Welded Floor Is More Durable.—A great advantage in favor of this construction is that the economical span length of simple span bridges can be increased to from 350 to 500 feet at the same costs per linear foot as for 200 to 300-foot spans. Or for any given span length and given sum of money, this new type offers a much stronger and a more durable structure for the same money.

The writer definitely classifies the roofing effect of the solid plate floor, as an advantage, when compared to the open grating floor, that will add many years of service life to the bridge and especially to the members and paint underneath. Certainly, the large flat surfaces of the arc welded floor are much easier to clean and paint and the number of exposed edges is at a minimum.

Saving Dead Load Is Not Always Economical.—The merits claimed for economy in dead load are often misleading. The savings are only possible where greater than minimum sections are required and only where members are governed in design by gravity loads. Often times wind loads, minimum slenderness ratios or architectural factors govern the design of a member and in such a case the saving in dead load is of no consequence. In fact, the heavier and more massive structure is generally the most desirable at equal cost.

The Steel Plate Is Homogeneous in All Directions.—The steel plate floor possesses another important feature of which no advantage was taken in this design. Regardless of the fact that this floor was fundamentally designed as a one-way slab, the steel plate is a homogeneous material equally capable of carrying stress in all directions simultaneously. This important feature permits the span length to be increased or the plate thickness to be reduced by designing the floor as a two-way steel-plate floor, in place of the one-way design as given on drawing, Fig. 1.

The advantage of full continuity is equivalent to 50% end restraint and represents approximately 10% economy in plate thickness as compared to the simple span. These advantages are called to attention because future designs can well take advantage of them.

This Arc Welded Plate Construction Is Advantageous in Many Fields.—It can be used with equal facility in heavy buildings and decks or for steel dams, drum gates, lock gates and many other hydraulic structures wherein the tributary loads have to be collected over large areas and carried to concentrated points of support. In building construction with the extension of a two way system ordinary building towers can be built with only four main corner columns and stressed steel walls with no other columns in the building.

Conclusion.—This paper has presented a new type of floor, designed for welding, and arranged in plan similar to ordinary one-way battledeck floor construction. It also proposes an alternate type of two-way framing in which two of these separate one-way systems, running at right angles to each other, can be superimposed upon one another

and through one another to obtain even greater economy by welding to a common floor plate. The floor plate is purposely made thicker and stronger than necessary so that the stresses from slab action are reduced to a low value. Then the principle of the stressed skin plate is applied and the excess strength of the floor plate is used to supply the missing top flanges of all the tee sections which are welded to the floor plate. This common top floor plate flange forms these tee sections into a network of I beams which support the floor plate, and the loads upon the plate, by superimposing an additional set of flange stresses upon those which already exist in the floor plate from slab action. These additional flange stresses are small in magnitude because the center of gravity of the combined section lies close to the floor plate. The floor plate serves as top flange metal for all sub-stringers, cross-beams, stringers and floorbeams and for short spans the stringers function as the girders themselves. In this manner complete thirty-foot span and sixty-foot span viaducts have been designed and estimated and found to be at least 25% less costly to construct than are ordinary conventional steel stringer and concrete slab viaducts.

This same thirty-foot span continuous floor was carried further and utilized as the bottom lateral system and the bottom chord of a welded 330-foot span tied arch truss. The 330-foot span bridge was found to be at least $106.00 per linear foot of bridge cheaper to construct than a standard bridge of the same length span with either a concrete slab or an open grating floor.

The electric arc welded floor described above accomplishes a definite saving in practically every type of steel bridge, from simple, fixed or continuous and rigid frame bridges to the most advantageous showing in the double deck bridge or in the tied arch and in the self-anchored suspension bridge structure wherein the floor can be put to additional uses for tieing the arch or resisting the thrust of the cables.

These economies will result in very large gross savings in the industry if this design or any similar design is adopted for general use. For instance, the emergency relief appropriation of 1935 for the United States Works Program of grade crossing projects set aside $196,000,000.00 for bridge structures. Twenty-five per cent of this sum is $49,000,000.00 which could have been saved from this single appropriation. Such a saving would have permitted many more major structures or even a great single additional structure as large as the Golden Gate Bridge to be included within this same appropriation.

The increased service life of this welded floor is evident. The floor slab has been made ¾ inch thick and has as much extra thickness over that required for slab stresses as is the total thickness of the one-eighth inch reticuline bars in a modern open grating floor. The deteriorating chemical and electrolitic action of concrete in contact with steel is eliminated and the roofing action of the solid deck undoubtedly increases the life of the bridge.

The natural advantage of the multiply stressed floorplate has been pointed out and the process of electric arc welding is the only method of fabrication which can make the most efficient use of this natural advantage.

Chapter IX—An Arc Welded Two-Span Steel Rigid Frame for Highway Grade Separation

By ROBERT S. TREAT and JOHN F. WILLIS,
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The structure furnishing the subject matter for this paper is one proposed to carry Den Road in the Town of Stamford, Connecticut, over the Merritt Parkway about 8.91 miles from its beginning at the New York State Line.

This Parkway is of the dual type, consisting of two thirteen-foot traffic lanes in either direction, separated by a center mall twenty-two feet four inches in width, sodded and copiously landscaped for beautification and the reduction of headlight glare.

All intersections, railroad or highway, regardless of their importance, are separated, thereby eliminating one major traffic hazard.

The reasons for the selection of this type of structure are many, yet all converge toward the common group of objectives sought; safety, reasonable economy, speed in erection over a completed portion of the Parkway, efficiency, appearance and adaptability to the existing conditions of the site.

While realizing that economy must receive its full measure of consideration, a strictly utilitarian structure would be neither desirable nor admissible. Only a structure comparable to those now extant on this Parkway and its neighbor the Hutchinson River Parkway would be tolerated.

Cognizant of all these essential qualifications, the writers have earnestly endeavored to create a structure of such character in complete harmony with its environs.

While this paper is primarily intended to deal with the advantages offered by the welded type of structure over the usual riveted type, the writers believe that a brief description, analysis and discussion of the two-span frame is not inappropriate.

In the subsequent discussion the writers have given considerable study and frequent reference to the works of Muller-Breslau, Cross and Morgan and especially A. G. Hayden, whose valuable book "The Rigid Frame" has suggested an ideal method of accumulating the moments and tabulating results.

A complete design of this structure has been made and all of the lengthy and somewhat laborious calculations are on file. It is intended, however, to only include in this paper a skeleton of the design, sufficient to convey the general method of procedure to anyone familiar with Mechanics.

The main dimensions of the frame, the span and height, are governed by the horizontal and vertical clearance requirements and have not been arbitrarily assumed. The depths of section at all points have been assumed according to the usual practice.

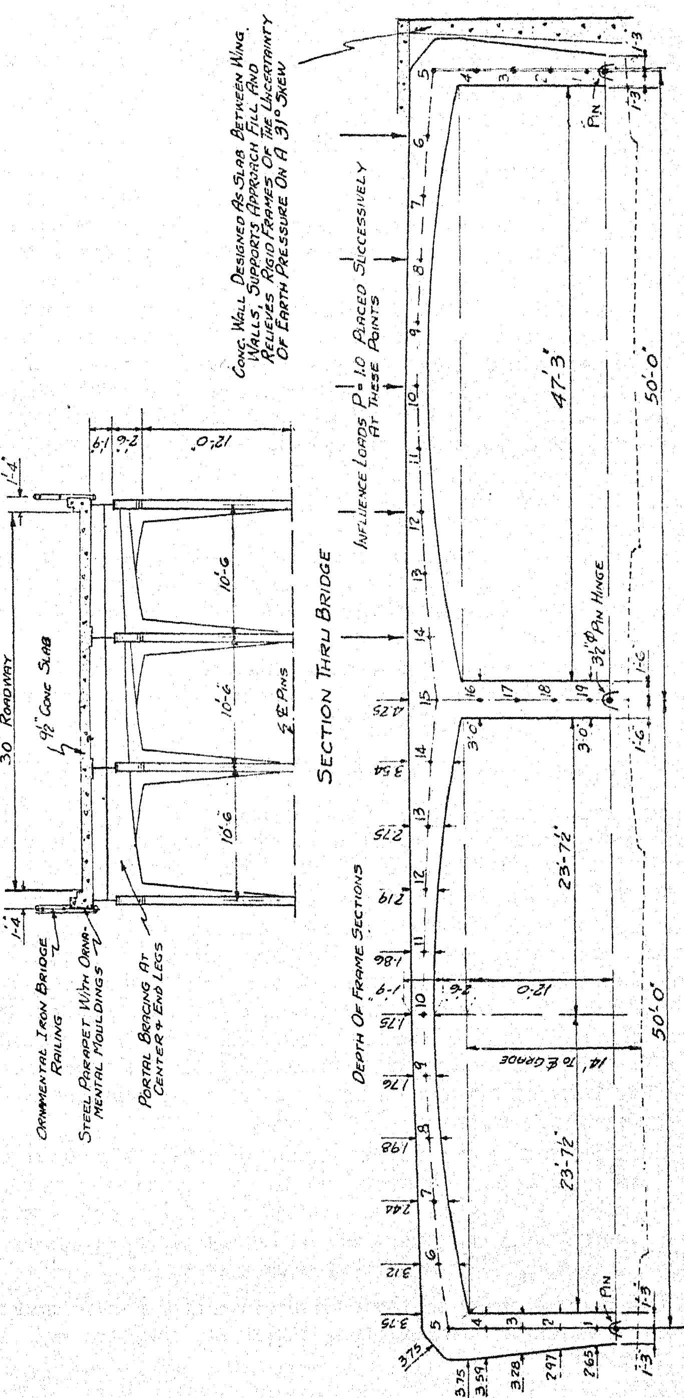


Fig. 1. Frame layout and design points. Scale: 1/8" = 1'-0".

It will be noted in the accompanying diagrams, Figs. 1, 2, 3, 4, and 5, that the frame is made up of 21″—112 lb.I's instead of the usual plate and angle construction.

The parabolic intrados of each rib is formed by splitting the I-Beams about 6″ from the bottom flange rather than along the center line of the web, thereby facilitating the bending. The "T" section thus cut off is bent to shape and a section of plate $\frac{9}{16}$″ in thickness, and having a form similar to a triangle with a curved hypotenuse is welded between the curved and straight portions of the girder, thus giving the frame its final shape.

The flanges facing the road on both legs and the center support will extend continuously to the underside of the top flanges of the ribs to which they are welded. These flanges are slotted to receive the rib webs and this joint is fillet welded, both sides. This method should prove to be an effective means of stiffening the rib at its point of maximum shear and negative moment, with a minimum of metal.

In the complete calculations there appears a table entitled "Frame Constants" in which are found the depths of sections, moments of inertia, the "X" and "Y" ordinates, the "M's" and all other data; tabulated for the purpose of deriving the numerical values of the constants as given in Fig. 2, Bracket 2. This table will not be included in this paper, only the summations necessary for designing are given as referred to above.

The fundamental formulas governing this design are shown in simplified form under Bracket I on Fig. 2. The modulus of elasticity "E" being a constant (29,000,000) as also is the increment "ds" (5 ft.) the elastic weight $\frac{\text{"ds"}}{EI}$ occurring on both sides of each equation becomes—$\frac{\text{"I"}}{I}$

Under Bracket 4, Fig. 2, C, D, and F are solved in terms of their respective summations, the completion of which leaves all in readiness for the compilation of the Influence Tables. The numerical values C, D, and F for the load in this position are given at the foot of Fig. 2.

After this procedure has been followed through for all load points, the moments and thrusts are accumulated for each point on the frame, tabulated and each coefficient multiplied by the dead load at the load points, thus the actual moments and thrusts are obtained. Adding these products, algebraically gives the total dead load moments and thrusts. The live load moments and thrusts are obtained in similar manner excepting that live loads are not applied at points having a coefficient of different sign than the resultant dead load stress.

An exception to this would be at a point where the total dead load moment was small as a result of the positive and negative coefficients nearly balancing. In this case the live load would be applied at the point or points having coefficients of the highest numerical values of both signs to determine if a reversal of stress existed.

NOTE:—Because of the relatively small values of the shears and the consequent low unit stresses resulting therefrom, they are not considered here.

The final stresses to be considered are those resulting from temperature. The highest temperature ever recorded at the site of this bridge was 105F. and the lowest 10F. from which data is assumed a rise of 45 deg. and a fall of 70 deg. F.

Finally the moments and thrusts arising from temperature, dead and live (plus 25% impact combined with the liveload) loads are combined and the sections investigated. The compressive stresses govern because of the thrust or direct stress being added to the fiber stress resulting from flexure.

It is impossible to develop the full strength of a frame (or in fact any other structure subject to bending and direct stress) at every point on its section; however, at the point of maximum positive moment, the crown, and at the point of maximum negative moment, the sections over the center support and knees, practically the full strength of section is developed. The center post and lower parts of legs are under-stressed and proportioned for appearance.

A partial table, summarizing moments and thrusts is given below. While in the complete design the stresses have been calculated for every point, only those at the three critical points are given here.

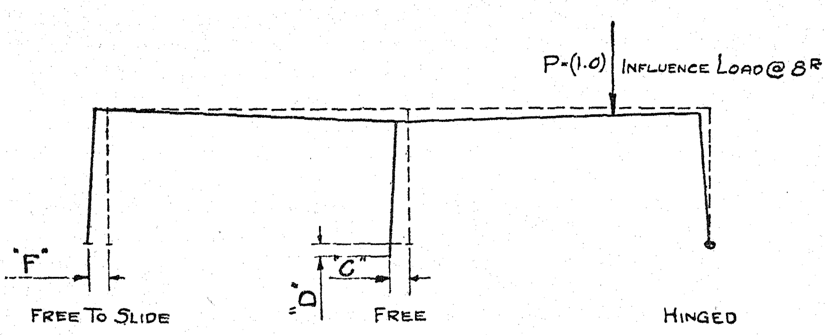
	Knee (Pt5)		C.L. Span (Pt10)		Center Leg (Pt15)	
	Mom #Ft.	Thrust #	Mom #Ft.	Thrust #	Mom #Ft.	Thrust #
DL	− 221503	+ 35950	+ 94600	+ 16720	− 368340	+ 16720
LL + I	− 287038	+ 32636	+ 197673	− 2714	− 353150	− 2714
Temp. (Rise)	− 75760	+ 5718	− (11870)	+ 5718	+ (71310)	+ 5718
Temp. (Fall)	+(117840)	− (8894)	+ 18480	− (8894)	− 110940	− (8894)
Total	− 584301	+ 74304	+ 310753	+ 19724	− 832430	+ 19724
Extra Fibre Stress	12,490 #/□"		15,505 #/□"		13,610 #/□"	

The absence of stresses appearing from earth pressures is explained partially on Fig. 1 and as follows: the skew angle being rather sharp, 31°—19′, it logically follows that the highly uncertain stresses from earth pressures will produce torsional stresses of a magnitude which could cause considerable difficulty in overcoming. To offset this possibility, the frame has been made completely independent of the backwalls. In place of the usual diaphragms between the frames which restrain the earth, a concrete wall is placed between the wingwalls and supported by them. An astonishing fact is that this type of construction costs but very little more than the former and the relief from the uncertainty of torsional stress is well worth the slight increase in cost.

This design is based on the use of hinges at the leg and center post footings and true hinges are used in Fig. 5, which is intended to show how the hinge shoes are assembled by welding, is a sketch of one shoe.

Figs. 4 and 3 respectively, show the manner in which the knee and section over the center post are assembled.

Cost Analysis.—Comparison of the relative costs of the all-welded type of structure with the all-riveted type follows:



GENERAL EQUATIONS

$$1\begin{cases} (1)\quad P\sum\frac{Mc\,Mp}{I} = C\sum\frac{Mc^2}{I} + D\sum\frac{Mc\,Md}{I} + F\sum\frac{Mc\,Mf}{I} \\ (2)\quad P\sum\frac{Md\,Mp}{I} = C\sum\frac{Md\,Mc}{I} + D\sum\frac{Md^2}{I} + F\sum\frac{Md\,Mf}{I} \\ (3)\quad P\sum\frac{Mf\,Mp}{I} = C\sum\frac{Mf\,Mc}{I} + D\sum\frac{Md\,Mf}{I} + F\sum\frac{Mf^2}{I} \end{cases}$$

NUMERICAL VALUES FROM FRAME CONSTANTS

$$2\begin{cases} \sum\frac{Mc\,Md}{I} = 8{,}429.08 & \sum\frac{Mc^2}{I} = 11{,}359.46 \\ \sum\frac{Mc\,Mf}{I} = 10{,}909\,46 & \sum\frac{Md^2}{I} = 15{,}665.08 \\ \sum\frac{Md\,Mf}{I} = 16{,}481.43 & \sum\frac{Mf^2}{I} = 21{,}584.16 \end{cases}$$

(P=1.0)

$$3\begin{cases} (1)\quad \sum\frac{Mc\,Mp}{I} = 11{,}359.46\,C + 8{,}429.08\,D + 10{,}909.46\,F \\ (2)\quad \sum\frac{Md\,Mp}{I} = 8{,}429.08\,C + 15{,}665.08\,D + 16{,}481\,43\,F \\ (3)\quad \sum\frac{Mf\,Mp}{I} = 10{,}909.46\,C + 16{,}481.43\,D + 21{,}584\,16\,F \end{cases}$$

SLOVING EQUATIONS IN TERMS OF $\sum\frac{Mc\,Mp}{I}$, ETC.

$$4\begin{cases} C = +.0001712\sum\frac{Mc\,Mp}{I} - .000005483\sum\frac{Md\,Mp}{I} - 0000\,8233\sum\frac{Mf\,Mp}{I} \\ D = -.000007616\sum\frac{Mc\,Mp}{I} + .0003248\sum\frac{Md\,Mp}{I} - 0002452\sum\frac{Mf\,Mp}{I} \\ F = -.00008231\sum\frac{Mc\,Mp}{I} - .0002453\sum\frac{Md\,Mp}{I} + 0002572\sum\frac{Mf\,Mp}{I} \end{cases}$$

SUBSTITUTING VALUES OF $\sum\frac{Mc\,Mp}{I}$, ETC. FOR INFLUENCE LOAD AT POINT 8 R

$$C = -.3960$$
$$D = +.2460$$
$$F = +.4498$$

Fig. 2. Numerical values of constants.

All Welded:—The first item to be considered is the cost of flame cutting the raw material. The lengths of the cuts are as follows:

Ribs and Legs—Splitting Girder	142′–0″
Center Post—Splitting Girder	12′–0″
Web from Flange at Knee	7′–0″
"Vees" to bend Upper Flange at Knee	5′–0″
Web from Flange over Center Post	2′–6″
Insert Plate 5/16″; Parabolic Arc	95′–8″
Insert Plate over Legs	5′–6″
Insert Plate over Center Post	2′–6″
Insert Plate in Legs 18′–9″ x 2	37′–6″
Total 5/16″ Metal	309′–8″

Use 310.0 ft./Frame

Removing webs from flanges where latter are to become the end stiffeners for the rib over legs and center post:

Legs	3′–9″ × 2	7′–6″
Center Post	4′–0″ × 2	8′–0″
	Total	15′–6″

Cost of cutting 5/16″ webs and plates:

Speed	100 ft.	per hour	
Labor	.75	per hour	
Gas	.02	per foot	
Labor Cost	.75		0.0075 Per Ft.
	100		0.020 Per Ft.
			0.275 Per Ft.

Assuming that the operator's wages are continuous but that he is only cutting one-third of the time because of handling and setting up the work, we have

Labor Cost .0075 × 3	0.0225
Gas, burning only while cutting ÷ 5% waste	0.0021
Net Total for Cutting 5/16″ metal	0.0435
Template, handling, delays, bevel burning, straightening	0.0545
Insurance 10% Labor Cost at Shop	0.0023
Gross Total	0.1003 Ft.

The cost will be estimated at $0.12 per foot for reasons to be given subsequently.

Forming the slots in the flanges of the legs and center post members is accomplished by burning out the web at the desired places, then burning thru the flanges for the proper width. The cost of this operation would be about twice the cost of web and plate cutting and it is so estimated.

From the above we have—

310 lin. ft. 5/16 metal at $0.12	$37.20
15.5 lin. ft. Flanges, etc. 0.24	3.72
Cost of cutting one frame	$40.92

CHECK—Three fabricating shops were requested to give an estimated cost of flame cutting steel of various thickness. The average of the answers given for 5/16″ stock was $0.009 per linear inch, all overhead included.

The price of $0.01 per inch or $0.12 per foot is therefore considered justifiable.

Total cost web and plate cutting four frames,
$40.92 × 4 .... $163.68

Next is the butt welding of webs to the insert plates; all welding with shielded carbon arc.

Actual length of butt welds, one frame	281′–6″
Allow for possible error, starting and stopping	1′–6″
Total	283′–0″

Data:

Labor	0.75 hr.	Labor Efficiency	66⅔%
Power	0.02/k.w.h.	Power Efficiency	50%
Welding Speed	21.0′/hr.	Arc volts	40
Carbons	$0.10 ea.	Arc amps	500
Fill. Metal	0.11 Lb.	Metal/hr	6.5 Lbs.
Autogenizer	0.30 Lb.	Consumption	22.0′ Lb.

Labor Cost $\frac{\$1.50}{21 \times .667}$	$0.0535
Insurance—10% labor	0.0054
Power Cost $\frac{20{,}000 \times .02}{1000 \times 21 \times .5}$	0.0381
Autogenizer $\frac{\$0.30}{22}$	0.0136
Filler Metal $\frac{\$0.11 \times 6.5}{21}$	0.0340
Manipulation of members, clamping, etc.	0.0530
Total	$0.1976

CHECK—Three fabricating shops, previously referred to, give the average cost of butt welding 5/8″ material according to above conditions as $0.155 per ft., all shop overhead included except idleness of operator during rest periods and while work is being turned, etc. The wages paid operators was $0.75 per hour in all cases.

Using a labor cost of $0.75 per hour, no idleness considered and combining with the other costs as given above, omitting manipulation and insurance, the total is $0.1214 per ft.

Inasmuch as a wage rate of $1.50 per hour and an efficiency factor of two-thirds have been used, the assumed cost of $0.20 per ft. is deemed conservative if not high. Incidentally the average welding speed obtained from above sources was 22.8 ft. per hour.

The next item under consideration for shop welding is the stiffeners, which are needed only for connecting the diaphragm channels to the frames. These stiffeners are 5″×3½″×⅜″ angles, connected to the frames by ¼″ fillet welds, continuous where the outstanding leg contacts the flange and in about two inch beads approximately one foot apart where connection is made to the web.

There are fourteen stiffeners either side of the two inside frames and fourteen on the inside of the two outer frames, making a total of eighty-four in all. The total length of these members is 168 ft.

With ten inches of continuous weld at either end of each stiffener there is a total of $\frac{84 \times 10}{12}$ or 70 lin. ft. of ¼″ fillet weld, continuous, for four frames.

One-sixth of the total length of the stiffeners gives the total length of the intermittent welding or $\frac{168}{6}$ 28 lin. ft. Allowing two lin. ft. for starting and stopping we have a total of 100 lin. ft. of ¼" fillet welding necessary to attach stiffeners.

The cost of this operation is as follows:

Labor	0.75/hr.	Labor Efficiency	66⅔%
Power	0.02/k.w.h.	Power Efficiency	50%
Welding Speed	33 ft./hr.		
Electrode	0.35 lb./ft.	¼"¢ Cost	$0.12/lb.
Arc volts	30		

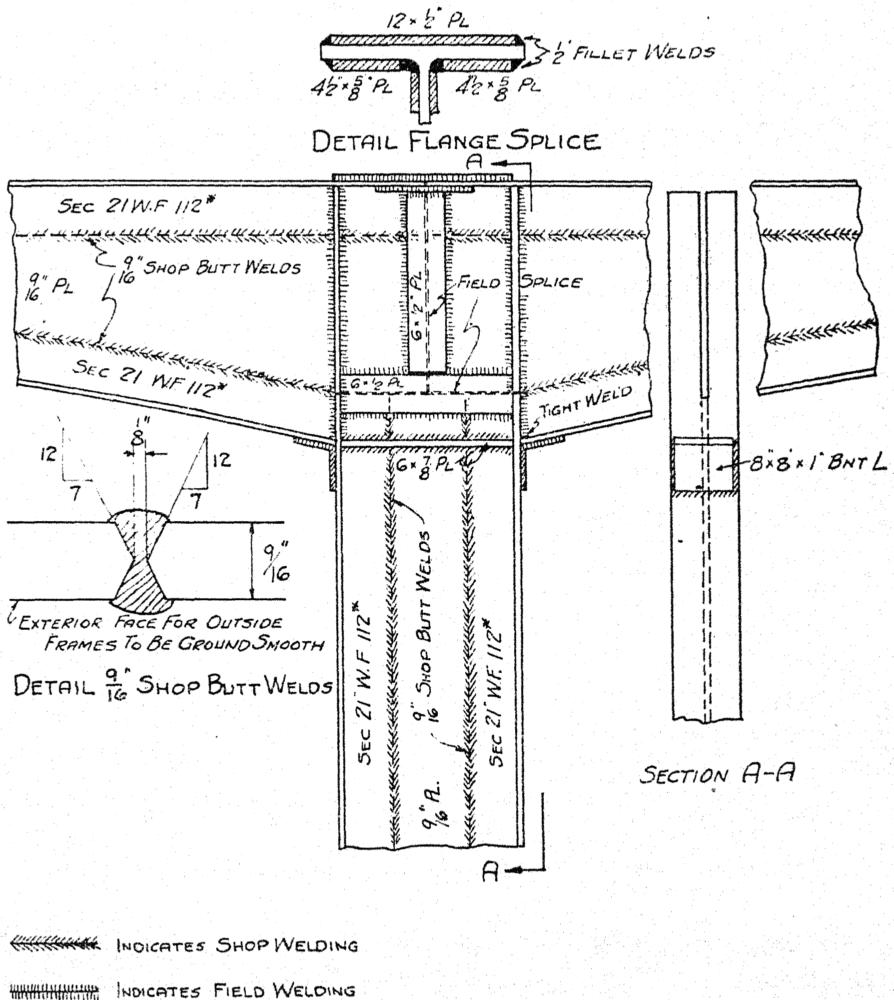


Fig. 3. Detail and welded field splice at center pier. Scale: ½" = 1'-0".

Arc amps............................... 190

Labor Cost $\dfrac{0.75}{33 \times .667}$ .... \$0.0410/ft.

Insurance 10% Labor.. 0.0041

Power Cost $\dfrac{190 \times 30 \times .02}{1000 \times 33 \times .50}$ .... 0.0069/ft.

Electrode .35 × \$0.12.. 0.0420/ft.

Total .... 0.0940/ft.

Use.. 0.1000/ft.

Total Cost of Welding Stiffeners to Webs—100 × \$0.1000............... \$10.00

The remainder of the shop welding on the frame proper consists of attaching the ½" pin plates to the webs of the frame legs.

Using 3½" pins and a bearing value of 24,000 lbs./sq. in. each plate is good for 24,000 × 3.5 × .5 or 42,000 lbs. to be developed by ¼" fillet weld. Using a shear value of 1600 lbs./in. (the maximum allowed by the specifications under which this structure will be built) it will be necessary to use 26.25 lin. ins. This will be carried continuously across the top, around the corners and down the sides sufficiently far to make the required length. (See Fig. 5.) Pin plates are 12" × 1'–6" × ½". There are about 3¾" of intermittent weld along the bottoms of the pin plates for stiffening, making the total length 30" per plate, 60" per leg and center post or 60'–0" for the entire structure.

The cost of this welding should not differ from the stiffener welding, therefore the same unit price is used.

60.0 × \$0.1000 .... \$6.00

Cutting and fabrication of the bracing whose function is to prevent side sway of the frames is next considered. No other description than that shown on Fig. 1 is necessary to explain the makeup of these members.

There are 174 lin. ft. of flame cutting of the ⅜" plates and angles used. Applying the same reasoning regarding the partial idleness of operators and other factors used in the frame main members, the cost will be as follows:

Labor	\$0.75 per hr.	Labor Efficiency 50%
Gas	0.015/ft.	5% Wastage
Speed	100 ft./hr.	

Labor Cost .... $\dfrac{0.75}{100 \times .5}$ = \$ 0.015

Insurance 10% Labor = 0.0015

Gas \$ 0.015 x 1.05 = 0.0158

Total ....\$ 0.0323

Cost of cutting stock for Sway Bracing
174.0' x .0323 = \$5.62

Assembling these members will require 486 lin. ft. of shop welding—⅜" fillet, — two inch beads at four inch intervals.

Because of the uncertainty of the stresses resulting from wind and tractional force and because of the skew angle, more welding is called for on these members than the calculations require.

Shop Welding Costs:

Labor	\$0.75 per hr.	Efficiency	66⅔ %
Speed	21' per hr.	Power operating factor	= .50
Electrode	.40 lb./ft.	Cost,— \$0.12/lb.	
Power \$0.02/k.w.h.	38V — 425A = 16.15 k.w.		

Work can be tilted to any position to facilitate operations.

Labor cost $\dfrac{\$\ 0.75}{21 \times .667}$	\$ 0.0536
Insurance 10% Labor	0.0054
Electrode .40 × 12	0.0480
Power $\dfrac{16.14 \times 0.02}{21 \times .5}$	0.0308
Total	0.1378
Clamping, Turning, Delays, Etc.	0.0422
Total	\$ 0.1800

Cost Shop Welding:

486.0′ × \$0.18 .... \$87.48

The final item for shop welding will be the shoes. These will have a base plate cut from a two-inch slab and the webs and bracing and diaphragm cut from one and one-half inch slab. (See Fig. 5).

Cost of Cutting Material:

TWO INCH PLATES

Speed	55 ft./hr.	
Gas	\$0.06/lin.ft.	
Labor	0.75/hr.	
Labor Cost	Labor Cost $\dfrac{0.75}{55 \times .667}$	\$ 0.0200
Insurance 10% Labor		0.002
Gas Cost		0.0600
Manipulation etc.		0.028
Total		0.1100

This cost is derived from curves and the same assumptions regarding idle time of operator and gas wastage are made as in cutting the girder webs and plates. \$0.03/ft. added to cover cleaning and truing up.

The unit price of \$0.14 per ft. as used may seem inconsistent in view of the material being two inches thick, whereas cutting girder webs and plates in the previous instance was estimated at \$0.12 per ft. However, while the cutting speed is slower and the gas consumption higher it must be remembered that there is no template work except locating anchor bolt holes, measuring lengths and scribing. The cuts are short and the work can be manipulated more readily and cheaply.

Length of cut, 2″ stock, 16″ per shoe or 16′-0″ for twelve shoes in the complete bridge.

Cutting cost 16′-0″ × \$0.14 .... \$ 2.24

ONE AND ONE-HALF INCH PLATES:

Speed	65 ft. per hr.
Gas	0.045 per lin. ft.
Labor	0.75 per hr.

Labor cost $\dfrac{.75}{65 \times .667}$	0.0174
Insurance 10% Labor	0.0017
Gas Cost	0.045
Manipulation, etc.	0.0279
Net Cost, cutting only	0.092

Using the same percentage of increase as in the case of the two inch stock, we have $0.1170 per ft. Use $0.12.

There are 140" of cutting of this size per shoe or 140'-0" total for all twelve shoes. The cost is, therefore:

140'–0" × $0.12	$ 16.80
Cost of base plate cutting	2.24
Total cost of cutting 12 shoes	$ 19.04

Before the component parts of the shoes are welded together four holes for anchor bolts must be drilled in each base plate. With high speed steel drills this operation could be accomplished in one hour per shoe by using first a 9/16" or 5/8" and following with a 1 1/8" size. The figure of one hour includes marking, center-punching, sub-drilling, drilling and all incidental handling.

One dollar and a half per shoe should cover the entire expense of this operation although some shops could undoubtedly lower this cost appreciably. Burning these holes is not permitted by the Specifications under which this structure will be built.

It will be necessary to cut holes for 3 1/2"ø pins in each shoe and frame leg (See Fig. 5). This can be accomplished with boring machine for a cost not exceeding $2.50 per shoe and leg complete.

On each shoe there are about 60 lbs. of metal wasted in cutting, which, at $0.0265 per lb. gives $1.59 to be added to the cost of each shoe or $19.08 for the entire twelve.

Welding Cost.—In this operation it is assumed that the work can be tilted into any position to facilitate welding.

There are 18'–0" of 3/4" fillet welding per shoe.

Speed	13.5 ft./hr.		
Labor	0.75/hr.	Labor Efficiency	66 2/3 %
Electrode	3/8"ø	1.46 lbs. Cost	0.12/lb.
Volts	36 Amps	350	first bead
Volts	40 Amps	500	second bead

Labor Cost $\dfrac{\$0.75}{13.5 \times .667}$ 0.0833

Electrode $0.12 × 1.46 .... 0.1752

Insurance 10% Labor .... .0083

Power 36 V × 350 A 12,600 watts
40 V × 500 A 20,000 watts

32,600 watts Or 32.6 K.W.H.

$\dfrac{32.6 \times \$0.02}{13.5 \times .5}$ 0.0996

Cost 3/4" welding/ft. .... $ 0.3664

Continuous welding of the shoe assembling would probably tend to warp or deform, therefore in order to overcome this difficulty, short beads are welded each side alternately on each part. As this will cause a delay and a consequent increase in cost of between $0.07 and $0.08 we shall add $0.0721 to the analyzed cost to bring the total up to $0.44 per lin. foot. This will include cost of peening for stress relieving if necessary.

In view of the fact that wastage of metal, time of handling, periodic idleness of both welding and cutting operators and liberal wage allowance are all taken into consideration, the estimated cost of $0.44 per ft. for welding alone is deemed conservative.

Total cost of shoes:

373 lbs. Steel	$ 0.0265	$ 9.8845
60 lbs. Steel waste	0.0265	.5900
18.0 lin. ft. ¾" fillet weld	0.4400	7.9200
Boring Pin Hole		2.500
11.67 lin. ft. 1½ flame cut.	0.1100	1.2837
1.33 lin. ft. 2" flame cut.	0.1400	.1862
Painting 2 coats lead and oil		.5000
Drilling Anchor Bolt Holes		1.50
Total Cost one Shoe		25.3644
Total Cost twelve shoes		304.3728

Net Cost to manufacturer, ready for shipping: $\frac{25.3644}{373}$ .0680/lb.

The final item for consideration after fabrication has been completed in shop painting-one coat of red lead and oil.

Exposed area to be painted is 9521 sq. ft. exclusive of the top flanges which come in contact with the concrete floor and remain unpainted.

Paint cost .... $ 1.75 per gal.
Paint coverage .... 630 sq. ft. per gal.
Gals. required $\frac{9521}{630}$ 15.11 say 16 gals.

Labor 6.00/day of 8 hrs. per man
1000 sq. ft. covered per day per man incl. delays, etc.
Time required $\frac{9521}{1000}$ 9.521 man days

Labor cost	9.521 × 6.00	$ 57.126
Paint cost	16.0 × 1.75	28.00
Total Cost shop painting*		$ 85.126

*painting of shoes not included

Transportation Costs.—Fabrication and shop painting now being completed, the matter of transportation from the shop to the site will be considered.

Loading and securing on cars will cost about $0.25 per ton. The longest member is slightly over 50 ft.; in consequence no special equipment is necessary for shipping.

The cost is mostly a matter of conjecture on account of the uncertainty of the distance of the successful bidder's shops from the bridge location. Assuming this distance as 200 miles the freight to Stamford would be $5.00/ton.

The unloading from freight cars to trucks should not exceed the loading cost, so the amount $0.25/ton will be used for this item.

The trucking cost will be about $0.30/ton mile for a distance of two and one-half miles or $0.75/ton at the site of erection.

Each member will be taken with a crane directly from the truck (and trailer) and placed in its final position, therefore this unloading cost will be absorbed in the erection costs.

The total weight of steel in this structure including the shoes is 103.176 or 51.58 tons exclusive of railing and ornamental steel paneling. Freight will be billed at 52 tons.

Loading on Cars	— 52 tons	@ 0.25	$ 13.00
Freight	— 52 tons	@ 5.00	260.00
Haul to site	— 52 tons	@ 0.25	13.00
Transportation to site			$286.00

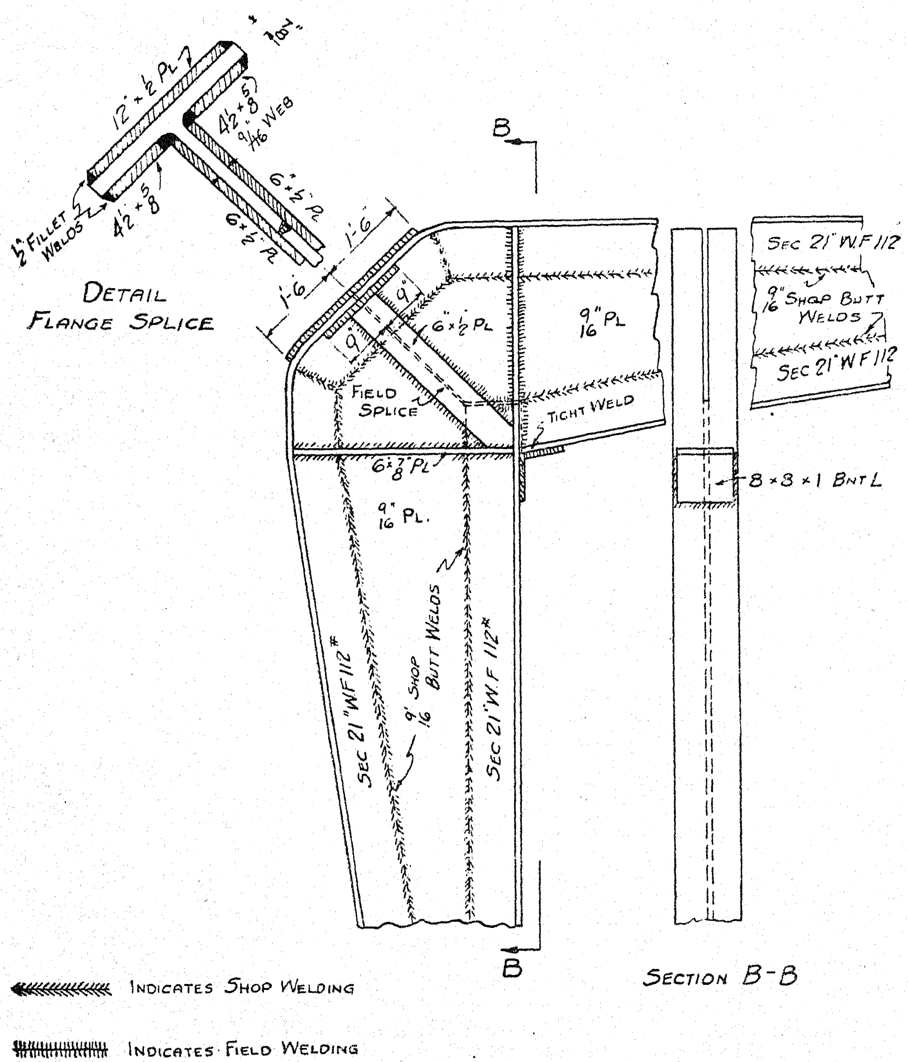


Fig. 4. Detail and welded field splice at knee. Scale: 1½" = 1'-0".

Erection Costs.—Erection costs on this structure, exclusive of field welding should compare favorably with erection costs of a riveted structure minus the field rivets. The jacking, blocking, etc. in this case should cost about the same as bolting up and unbolting the riveted type.

There are 20 main members, exclusive of diaphragms and cross bracing. The cost of manipulating these into position will, of course, vary according to the contractor's equipment, but on jobs of a similar character the total cost averaged for three cases, $14.00 per ton, exclusive of falsework. There was an average of 108.25 tons per bridge and an average of 2150 field rivets in each.

Total Cost was—108.25 × $14.00	$1515.50
Deduct—2150 Rivets at $0.25	537.50
	$ 978.00

$$\frac{\$\,978.00}{108.25} \text{ gives \$9.12 per ton}$$

The amount of $10.00 per ton, exclusive of falsework and welding will be used here.

Falsework.—By the time construction on this work is started the entire pavement will be in place and the Parkway open to traffic, at least in this vicinity. It will, therefore, be necessary to construct one half at a time in order to keep the other open to traffic.

About four thousand board ft. of rough lumber will be required to support the steel during erection, which amount includes all staging for welders and all cross-bracing and ties for one-half the span plus the center supports.

As the lumber will have a high salvage value, unit prices of twenty five dollars ($25.00) M.B.F. for cost and transportation and ten dollars ($10.00) M.B.F. will be used for erecting twice and dismantling twice.

The falsework cost therefore is:

($25.00 + $10.00) × 4 = $140.00

Field Welding.—With the exception of the diaphragm and sway bracing, all the field welding will be ½" fillets. The total length of this is as follows:

96 Lin. Ft. Overhead at Knees
48 Lin. Ft. Overhead Center Posts

144 Lin. Ft. Overhead—Total

The welds on the undersides of the inclined splice plates are classed as overhead and are included in the above, although not strictly in that category.

Of the remaining 496 lin. ft. 352 ft. are vertical and 144 lin. ft. are flat welding.

In the following analysis of cost the operating factors or labor efficiency of .30 for overhead work, .45 for vertical work and .60 for flat work will be used.

Welding speeds of 6.5 ft./hr. will be estimated for overhead and vertical work and 18 ft./hr. will be estimated for flat work.

It will be noted that in calculating the transportation costs the gross weight of 52 tons was used, which included the shoes. In the subsequent field welding costs the cost per pound is based on the actual weight of the structural steel in the frames, diaphragms and sway bracing.

In figuring the field welding cost on this job the designers have diverged from the usual practice of making an analysis based on labor, kilowatt hours, electrode costs, etc., as was done in the case of shop welding.

A general contractor will bid on this bridge and sublet the steel work to a steel company offering the most attractive figure. This figure will be a delivered price at Stamford, Connecticut. The general contractor will then assume responsibility of hauling to the site and erection. Should, however, the steel contractor include erection in his cost he would, without doubt, rent local equipment and labor to do the welding.

Commercial welders have made bids for this and similar classes of work of an average of $16.00 per day for use of the machine alone, or $24.00 per day for machine and an expert operator, and all necessary materials, electrode, autogenizer, etc. In either case, all transportation, both ways fuel and all other overhead were included in the price quoted.

Inasmuch as the writers believe that commercial welding should be encouraged and that it would be good economy in the case of this structure, field welding will be based on a cost of $24.00 per diem for labor, power, and materials. (Day based on 8 working hours—$3.00/hr.)

Overhead Welding Cost

$$\frac{\$3.00}{6.5 \times .30} = \$\ 1.538/\text{ft.}$$

Vertical Welding Cost

$$\frac{\$3.00}{6.5 \times .45} = 1.025$$

Flat Welding Cost

$$\frac{\$3.00}{18 \times .60} = 0.278$$

Total Cost Field Welding Frames

144 Lin. Ft. Overhead	@	$1.538	$ 221.48
352 Lin. Ft. Vertical	@	1.025	360.80
144 Lin. Ft. Flat	@	0.278	40.03
		Total	$ 622.31

The final field welding of the structure proper will comprise attaching the sway bracing.

There are 480 lin. ft. of intermittent (240 lin. ft. actual) of ⅜" fillet vertical welding necessary to attach the sway bracing, and 120 lin. ft. of ⅜" fillet vertical (60 lin. ft. actual) welding necessary to attach the diaphragms. Total ⅜" vertical = 600 lin. ft.

Where the top flange of the diaphragm channel comes in contact with the stiffeners there are 5 lin. in. at each end of channel, ⅜" flat welded continuous fillet. The same applies to the bottoms of the channels which is classed as overhead welding. There are 20 lin. ft. of each of these welds. We have then as a total

Vertical Welding—intermittent	480 lin. ft.
Flat Welding—continuous	20 lin. ft.
Overhead Welding—continuous	20 lin. ft.

The same hourly costs as used in the field welding of the frame will apply here. The same operating factors will be used also, but speed will be increased as follows:

Flat Welding	20 ft./hr.
Vertical Welding	9 ft./hr.
Overhead Welding	7.5 ft./hr.

The costs of this operation are as follows:

Overhead Welding

$$\frac{\$3.00}{7.5 \times .30} \qquad \$\ 1.333/\text{ft.}$$

Vertical Welding

$$\frac{\$3.00}{9.0 \times .45} \qquad 0.741/\text{ft.}$$

Flat Welding

$$\frac{\$3.00}{20 \times .60} \qquad 0.25$$

Total Cost Field Welding Diaphragms and Bracing:

Overhead	—	20 lin. ft.	@	1.333	$ 26.67
Vertical	—	480 lin. ft.	@	0.741	355.68
Flat	—	20 lin. ft.	@	0.25	5.00
				Total	$387.35

There remains now the ornamental moulding, the embossed steel panel plates, which extend along the parapets and the open ornamental grill work on the legs and center support.

The quantities are as follows:

Parapet Paneling	380 Sq. Ft.
Moulding Between Flange & Web	380 Lin. Ft.
Grill Work on Legs & Post	396 Sq. Ft.

The costs given below are as submitted by a firm specializing in this class of work and include all necessary lugs for attaching, shop painting, and delivery at the site but not installing.

Parapet Paneling 1/8" thick	$ 0.35/sq. ft.
Moulding—12 gall.	0.22/lin. ft.
Grill Work 3/16" thick, any design	0.55/sq. ft.

To install this ornamentation will require about 190 lin. ft. of intermittent weld, 1/4" fill, to attach the paneling to top of outside frame; 760 lin. ft. of the same for attaching moulding; this could be done in the shop and at a cost of $0.10 per ft. gross, and is so estimated, and 264 lin. ft. of this same size and kind of welding to attach the grill work. As this welding is straight ahead work and speed should average 25 ft. per hour and at a cost of

$$\frac{\$3.00}{25} = 0.12/\text{ft.}$$

Cost of ornamental work in place:

380 Sq. Ft. Paneling	@	0.35	=	$ 133.00
396 Sq. Ft. Grill	@	0.55	=	217.80
380 Sq. Ft. Moulding	@	0.22	=	83.60
454 Lin. Ft. 1/4" Field Weld	@	0.12	=	54.48
760 Lin. Ft. 1/4" Shop Weld	@	0.10	=	76.00
Total Cost Ornamentation in Place				$ 564.88

Field Painting.—The final color scheme will probably be a combination of light green and aluminum, two coats.

Area to be covered = 9251 Sq. Ft.
Coverage 2 coats 375 Sq. Ft./gal.
Cost $ 2.25 gallon
Labor $ 8.00 per day or $1.00 per hour
1000 Sq. Ft. covered — 1 coat per man in 8 hours.

Paint Cost

$$\frac{9521}{375} \times \$\,2.25 = \$57.13$$

Time Required

$$\frac{9521}{1000} = 19.05\text{—say 20 man days}$$

Labor Cost

$$20 \times \$8.00 = \$160.00$$

Cost Field Painting $217.13

NOTE: Under the item of gas cutting stock for frames there should also appear in addition to the amount of $163.68 the cost of cutting the remaining stock which is 99′–2″ or say 100 lin. ft. all lumped at $0.14/ft. which adds $14.00 to the above bringing the total to $177.68.

Estimated Total Cost of Welded Frame.—(All steel in place, ready for continuation of job).

Gas cutting stock for frames	$ 177.68
Shop welding	132.09
Machining and grinding outer surface	22.56
Stiffeners, weld, in place	11.71
Welding pin plates	7.03
Shoes, complete as shown	400.38
Diaphragms and swaybracing, cut and weld	93.10
Shop painting, except shoes	85.13
98,700 lbs. structural steel at mill @ $0.0235	2319.45
Freight to shop on above @ $0.003	296.10
52 tons considered for freight from shop, haul, load and unload only	
Transportation as shown	286.00
Erection 98,700 lbs. @ 0.005	493.50
Falsework as described	140.00
Field welding frames	622.31
Field welding bracing, etc.	387.35
Ornamental paneling, etc.	564.88
Ornamental railing — 200 Lin. Ft. @ $7.00	1400.00
Field painting	217.13
Total Cost, All Steel In Place	**$7656.40**

All Riveted.—The same principles of design are, of course, applicable to both the riveted and welded types. The riveted type will have the same general dimensions, shape, and contour, as the welded type. The section at the center will have to have a section modulus equal to the 21″—112 lb. I beam used in the welded frame which was 249.6. Without repeating the calculations here, the crown section will be composed of a web plate 21″ × ½″, top flange angles 6″ × 4″ × ¾″, and lower flange angles 6″ × 4″ × ½″ and a 14″ × $\frac{5}{16}$″ cover plate. The moment of inertia of this section is 2651.54, and the section modulus is 252.5.

The weight per foot at the crown is 130.0 lb., and the same weight and section modulus could be obtained by leaving off the lower cover plate and using 6″ × 6″ × ¾″ flange angles, making the appearance even less pleasing.

The legs and center post on the riveted type would be made up of the same combination as the lower flange of the rib and would weigh in proportion. The field splices would be made in the same manner; that is, by extending the flange angles of the legs and post up to the bottom of the upper flange angles of the web. Fillers and complicated cutting would also be required. On account of the curved lower flanges of the ribs, multiple punches could not be used to advantage.

Flame Cutting Costs.

Length of cuts	
Parabolic arc on rib plates ½″	95′–8″
Legs, plates ½″	14′–0″
Web plate over legs	10′–0″
Web plate over post	4′–0″
Flange angles, legs	10′–0″
Flange angles, ribs	6′–8″
Cutting per frame	140′–4″
Cutting four frames	421′–4″
Stiffeners—4 frames	30′–0″
Channel diaphragms	52′–6″
	503′–10″ Total
Say	504′
504′ at $0.12	$60.48

Using a maximum spacing of six inches for all shop rivets, there are, in one frame

Intrados—or lower flange of rib	576
Top of rib	200
Knees	16
Legs	144
Center Post	72
Stiffeners	356
Total—one frame	1364
Total—four frames	5456

Sway bracing, —
20 plus 36 plus 44 = 100 per brace × 12 braces = 1200
Total Shop Rivets = 6656

Field rivets

Knee—develope $\frac{9}{16}'' \times 12''$ @ 18,000 lbs. (10.5 net w) top flange

$$= \frac{5.9 \times 18{,}000}{5960} = 18 \text{ rivets each side} = 72 \text{ for 2 knees}$$

Center post—top flange, same	=	36 for one
Main stiffener or vert. flanges	=	30 for all
All splice plates		46 for all
Knee angles		16 for all
		128 riv. one frame
		512 four frames
Sway bracing, 78 per frame—12 fr.		936
Channel diaphragm, 30 @ 6 inches		180
Total Field Rivets		1628

On inquiry, the writers have found that the lowest estimated cost per unit for shop driven rivets where multiple punches cannot be used is $0.08. This gives the cost of driving all shop rivets, —

6656 @ $0.08 .... $ 532.48

Where the groups of field rivets are scattered as in this frame the greatest number which can be driven is about 175 although the average is somewhat less.

The following is the cost per day:

3 men—2 riveting, 1 bucking @ $12.00 day	=	$36.00
1 heater @ $12.00		12.00
Coal, etc.		1.00
		$49.00

$$\text{Cost per rivet} = \frac{\$49.00}{175} = \$0.28 \text{ .... Say } \$0.28$$

The cost of field rivets therefore is, —
1628 @ $0.28 .... = $455.84

The total weight of steel, exclusive of shoes, railing and ornamental panels in this structure is 105,400 lbs. It has been generally estimated that the shop cost of fabrication on structures of this type, which includes templates, drafting, handling, marking, etc., but exclusive of shop painting, riveting, and cost of metal, and cutting, is from $0.0125 to $0.0175 per lb.

Using the figure $0.0125, we have the cost of shop handling as described, —

105,400 @ $0.0125 .... $1317.50

The shop painting would cost about the same as in the welded frame and is, — $ 85.13

Assuming that the shoes are the same dimensions as the welded ones, but of cast steel. (Cast iron and built up riveted shoes are outlawed by Specifications).

These shoes weigh 373 lbs. each. The prices the State has received on shoes similar to these has ranged from \$0.18 per lb. upward. If a profit of 20% is contained in this price, the cost to the shop is $\frac{\$0.18}{1.2} = \$0.15$ per lb. At this price the cost of the 12 shoes ready for shipping would be, —

373 × 12 × \$0.15 .... = \$671.40

Transportation.

The total weight of steel including shoes would be 109,876 lbs., and freight would be billed at 55 tons.

Using the same transportation charges as in the case of the welded structure, we have, —

Loading, etc., on cars	\$0.25/ton
Freight	5.00/ton
Unloading	0.25/ton
Haul	0.75/ton
Total for trans. to site	\$6.25/ton

Cost of transportation to site.

55 tons @ \$6.25 .... = \$343.75

Falsework necessary would not differ essentially from that estimated for the welded structure; therefore, the same figure is used.

Cost of Falsework .... \$ 140.75

The cost of erecting and bolting up as mentioned previously would be about \$14.00 per ton (actual) falsework and field rivets excluded.

Like the shop painting, the field painting would cost about the same as that item on the welded structure, \$ 217.13

The ornamental steel railing is identical on both types and the cost therefore is, \$1400.00

The ornamental paneling and grill work is likewise identical and will cost, \$ 564.88

The cost of the raw material at the mill would be

105,400 lbs. @ \$0.0235 .... = \$2476.90,

exclusive of shoes, railing and ornamental work which are estimated completely by themselves.

The freight on the above raw material would be

105,400 lbs. @ \$0.003 .... = \$ 316.20

ESTIMATED COST OF RIVETED FRAME

All steel in place, ready for continuation of job.

Gas cutting stock for frames	\$ 60.48
Shop rivets 6656 @ 0.08	532.48
Field rivets 1628 @ 0.28	455.84
Fabrication as explained	1317.50
Shop painting	85.13
Shoes, as explained	671.40
Transportation as above	343.75
Falsework	140.75
Erection as explained	737.80
Ornamental paneling & grill work	564.88
Ornamental railing	1400.00
105,400 lbs. steel at mill	2476.90
Freight, mill to shop	316.20
Field paint	217.13
Total Cost, all steel in place	**\$9320.24**

As shown in the welding cost table the total cost of all steel in place is estimated at \$7,656.40 for the welded frame, shoes included. Deducting the costs of the railing and paneling which have no bearing on the structural steel costs, we have a total of \$5,691.52. The total cost to the contractor then is

$$\frac{\$5691.52}{103176} \text{ or } \$0.0552 \text{ per lb.}$$

Figuring a profit of about 20% brings the bid price to \$0.067 per pound.

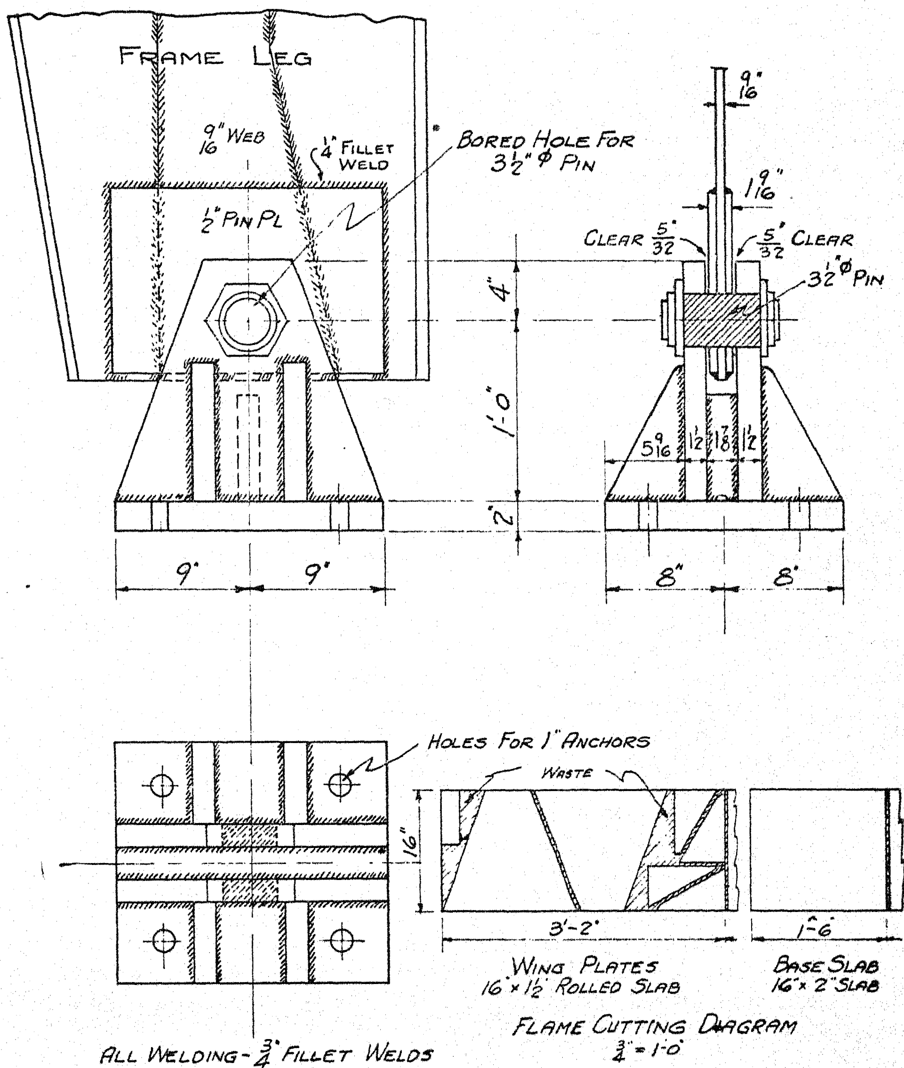


Fig. 5. Detail of built-up welded shoe. Scale: 1½" = 1'-0".

The cost of all steel in place for the riveted type is estimated at $7,355.36 with the railing and paneling deducted as before. The total cost of the 109,876 pounds in place, including shoes, would then be

$$\frac{\$7355.36}{109876} \quad \text{or } \$0.6694 \text{ per lb.}$$

Allowing the profit of 20% as before brings the bid price to $0.0803 or $0.0800 as used.

In the foregoing it has been shown that the total cost of the welded structure—steel only—would be $7,656.40 and the riveted type would be $9,320.24, fabricated, erected, and painted, all complete in place ready for the deck or any other phase of construction.

Throughout the cost analysis of each structure the utmost conservatism was adhered to, to prove beyond doubt that the welded structure was the less expensive. In every assumption, welding costs were estimated high and riveting costs low.

The A.A.S.H.O. Specifications under which this design was made are much more conservative toward welding than need be, shear values of fillet welds are 25% lower than American Welding Society specifications consider good practice.

Despite these conditions, the welded structure is cheaper to fabricate and less metal is used.

There is little doubt that when this structure is placed in the shops, even greater economy will be effected than is here shown. When the designer's plans go to the steel contractor, practically all the information the shop requires is thereon contained. There is no complicated work for the draftsman to lay out his rivet and punching schedule. The same applies to the template shop. One fabricating shop which has built several riveted rigid frames (single span) in New York and New England, estimates the shop and drafting room costs at $0.0275 to $0.03 per pound exclusive of metal. This, however, sounds high.

In the matter of erection and the comparison of field welding costs with field riveting, welding again has a decided advantage.

An outstanding example of how a contractor may sustain serious losses was brought to the writer's attention recently. A field splice near the knee of a single-span steel rigid frame was called for. Through an error on the part of someone unknown to the writer, the open holes did not come "fair" and it was impossible to bolt the frame into position. Partially dismembering and installing new plates, properly punched, and numerous other plans were suggested. Finally with the consent of the engineer and the advice of the designer, the difficulty was solved by reaming the holes to receive one inch rivets. This reduced the flange area somewhat but the overstress was not serious. This error cost someone over one dollar ($1.00) per rivet, or $368.00, together with a delay of several days in the fall when the working season was growing shorter and the concrete deck was still to be placed. Had this been a welded structure the difficulty would have been avoided. Also, had the contractor done as the designer suggested, that is, used welding for his splicing, money would have been saved as well

as time. Although the structure was designed and the contract awarded on the basis of riveting, welding would have been permitted in this emergency had the splices been arranged differently.

In the foregoing data the quantities of steel were estimated and checked with the utmost care and the weights should not vary more than one or two per cent in the case of the welded structure.

In the case of the riveted structure, only sufficient detail was made to give the designers the information for a fairly close approximate estimate. If completed drawings were made, as in the case of the welded design, it is quite possible and most probable that there would be an increase of from five to ten per cent in the weights and a substantial increase in the number of both shop and field rivets.

With reference to the shoes, it will be observed that when cast steel was estimated the quantity used was the same as the welded slabs. Were the same strength required, the main bearing webs of the castings would have to be increased in width, thereby increasing the weight. Cast steel shoes would have cored holes for the anchor bolts and pins. Reaming the pin holes would of a certainty be required, and possibly the anchor bolt holes also. Machining the casting bases, or at least rough grinding, would probably be necessary also. However, none of these possible contingencies has been taken into account in figuring the cost of the cast steel shoes. The welded shoes need no machining on the bases and the cost of drilling anchor bolt holes and boring pin holes was taken care of in the analysis.

Another item which has been estimated high for the welding was the power cost at $0.02 per k.w.h. Two well-established structural shops in Connecticut merely consider electricity as a small part of their overhead, although they do not generate their own. Owing to the great volume they use its cost to them is about $0.01 per k.w.h. In many sections of the State $0.02 per k.w.h. is the domestic rate after the consumption reaches a certain amount.

Finally, the following conclusions are drawn regarding the relative costs of the welded and riveted frames: The difference in cost in favor of the welded structure is estimated at $926.04 or the riveted type is about 12% higher.

The above figures are made in such a manner as to show the welded structure the cheaper in spite of the handicap of inadequate specifications, which are too conservative, and the riveted type being given the advantage of having a less accurate analysis.

The cost of field welding per day has been determined and the quantity of the operators' work carefully estimated while the wage of $1.50 per hour has been used in a vicinity near the New York labor zone where the rate is much higher and will, perhaps, affect labor at this site.

Benefit to Industry.—The structural steel industry, throughout its various ramifications and its co-ordinated industries, should reap benefits of no small degree when the public becomes educated to this type

True, this structure is small both in size and in cost where, in these days, gigantic structures are measured in terms of miles and millions. However, this case is a matter of "mass production", not of building one. This particular one, the first of its kind in the state, is about one hundred foot span and carries a thirty-foot roadway.

The Merritt Parkway which tentatively ends at Stratford, Conn., some thirty miles beyond this bridge, is to be continued northeasterly to the Massachusetts Line near Worcester under the name of the "Wilbur Cross Parkway" in honor of the present Governor. This new parkway will be over eighty miles in length in addition to various feeders to the cities of Hartford, New Haven, Meriden, and Middletown, making perhaps, a total of one hundred miles.

There will be about one hundred structures required to separate all grades and cross all watercourses encountered, including major crossings over the Housatonic and Connecticut rivers.

The majority of the bridges acting as grade separations will be of a span which can be most economically constructed of steel. Some will be of the same type as this, some single span, and in one case there is a possibility of a triple span where a railroad comes into the picture.

The architectural treatment can be varied in many ways; even stone facing can be used with the steel acting only as a supporting agent, the stone alone visible on the faces.

Whatever may be the type or architectural ornamentation, etc. welding will be the means of assembling, if it can benefit the fabricator by lowering his cost and the erection costs and thereby the cost to the public.

With safety campaigns now so prevalent, the "super-highway" naturally comes to the fore and takes its place as a contributing factor. It naturally follows that the structure separating the grades is of primary importance.

As has been stated before, this structure is small, but small bridges play a more important part, and industry benefits more by them than the large ones because the total amount of money spent for small bridges in one year far exceeds the amount spent for the large ones in most localities in the north. For instance, the only large bridge built in Connecticut since 1920 is the one over the Connecticut River between Portland and Middletown, now* nearing completion and costing about $3,000,000.00. Yet, since 1935 on the Merritt Parkway and other parts of the State, far more than that amount has been spent on small structures.

In conclusion, it may be stated in making comparative estimates of the two types that while only a small saving in cost to manufacture is shown in the initial attempt, this saving is estimated by giving the more expensive type the advantage in the analysis.

When a structure can be produced in steel to compare in every way in appearance to those of uncertain strength and short lived beauty, it is logical to assume that type will sell itself. The public buys

*At time of writing paper.

with its eyes, and with unsightly rivets eliminated and the knowledge that the reliable and time proven steel is in the background, there is little doubt as to the future of the welded steel frame.

Finally, an infant industry is being nourished, despite the fact that the "infant" is standing on its own feet and justly asserting its rights, it needs support and doubtless will receive it.

Labor will also be another beneficiary as arc welding is promoted. Men who are now experts in riveting are learning the art of welding and a change over will not be a detriment to them, as the transition is gradual. Men skilled as welders will apply their ability in some of the many fields outside the structural field when work is dull in the latter industry.

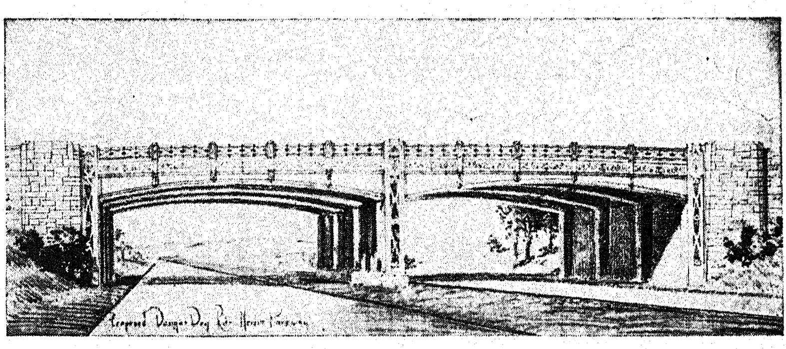


Fig. 6. Proposed design of Den Road, Merritt Parkway.

Advantages to the General Public.—When two intersecting grades are separated, the motoring public reaps the benefit of having a major traffic hazard removed, as stated in the introduction. This effect is physical and to some extent mental. The benefits derived after the mental and physical hazards have been eliminated are then dependent on the economy of the type selected over any other, and to no less extent the grace and esthetic appeal.

When a material highly lauded for its "permanence", "durability", "beauty", and all the rest of the long line of sales promotion adjectives begins to show serious signs of deterioration in a few years after its debut, the public begins to wonder if its choice of material in the structure was a wise one.

In the structure herein described, the designers are presenting to the public somewhat of an innovation, which, it is hoped, will meet with approval, both as to cost and appearance.

Most of the bridges over and under the Parkway are quite massive in appearance although quite pleasing to the eye—at present. The Parkway on a gentle up-grade approaches this bridge from both directions, leaving it on the brow of a hill. A heavy massive structure here would certainly be most inappropriately placed. It takes only logical reasoning to visualize the slender graceful lines of the structure as illustrated herewith adorning and not marring the landscape of

this scenic drive. This slenderness could only be obtained by the use of steel, and the smoothness only by the method of welding the members together.

There will be no mysterious cracks appearing from unaccountable causes, nor will any other signs of deterioration become visible, or occur other than those resulting from atmospheric conditions.

Painting the outer parts of the bridge at intervals of not less than five years would bring back the original for an amount not exceeding $45.00 per year. Lasting beauty is worth this much.

Should a radical departure from an existing color scheme be desired in the future it could be easily accomplished. The absence of rivet heads tends to reduce the cost of painting.

What will make its greatest appeal to the public is the fact that, excluding the strictly "utilitarian" structure, the welded bridge here presented is the least expensive type that could be built, taking all necessary qualifications into consideration.

The saving on the individual structure, is small, comparatively, but as the number of structures of like character increases, the saving to the public will increase more than proportionately.

In conclusion, it is inevitable that the motoring public will receive more for its taxes, that industry will profit by a self-promoting commodity and labor will benefit by the advent of an ever-expanding trade or profession.

An elevation drawing, (See Fig. 6), was made to a reasonably large scale, and all details of the ornamental work carefully worked out. This drawing was reproduced in perspective by Mr. George Dunkelberger, architectural draftsman with the Connecticut Highway Department. This picture resembles the finished structure as closely as it is possible, considering that it has yet to be built.

This bridge will have a reinforced concrete deck and a roadway 30 feet in width.

The exact details of the ornamental steel railing have not been worked out, but its appearance will be essentially the same as shown in the picture.

The wingwalls will be of concrete, ashlar faced as shown.

The only concrete showing from the Parkway will be the bottom of the deck slab and the backwall all remotely visible.

Chapter X—Five-Span Deck-Plate Girder Highway Bridge Redesigned for Arc Welding

By RICHARD DE CHARMS,
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The art of welding has been advanced to a point where its dependability has been proved and fabricators are adapting their shops for its use and machines have been designed that permit erection of structures at isolated places so that the all-welded bridge is being accepted. This has been made possible by the experiments and the application of arc welding to the problem because of the real efficiency of the method and the greater reliability of the results. There is, therefore, a fertile field for development of the use of arc welding to the type of bridges that are so necessary to link the highways which carry our modern motor transportation.

A type of bridge that lends itself readily to welding and shows marked advantages over riveting is the plate girder. This is true not only of the simple span but also of the bridge incorporating the principle of continuity of the main members. Design methods for continuous plate girders have been simplified so that this type is being adopted by designers to meet the demands of economy in our highway bridges and true continuity can be gained better by welding than by other means. But each bridge is a problem in itself and has to be designed for peculiar conditions imposed by the site so that it is hard to draw general conclusions as to the value of different methods of fabrication unless they are based on the application to a specific problem. Therefore, a detailed analysis comparing the phases and parts of a structure incorporating plate girders for both simple and continuous spans is timely. It is with the idea of presenting data that will be of value in advancing progress in the design and construction of moderate span steel highway bridges of these types by arc welding that this paper is written.

The paper covers the redesign of the structural steel for arc welding of a deck-plate girder highway bridge 76 feet wide by 444 feet long that was constructed by riveting. The bridge is shown in Fig. 1. As the writer had charge of the construction of the entire project for the general contractor, he had access to the field data relating to actual weights, cost and time of erection. These have been used as a basis for comparison with the redesign to show the relative merits of the two methods of fabrication.

The original problem involved a number of difficulties that were imposed by the site and were met by the designers in a practical way. A main highway through an urban district was carried across a navigable stream by an old wrought-iron three span truss bridge that had long been inadequate to handle modern traffic. The alignment was bad and the roadway only 20 feet wide so that with an average

traffic count at the bridge of 5,800 vehicles in eleven hours, transportation was seriously held up at rush hours.

The stream was shallow and flowed over bed rock that had been cut down to permit inland waterway navigation that required greater clearance than allowed by the old bridge. Fig. 2 shows the requirements of clearance, grade and skew that affected the superstructure of the bridge.

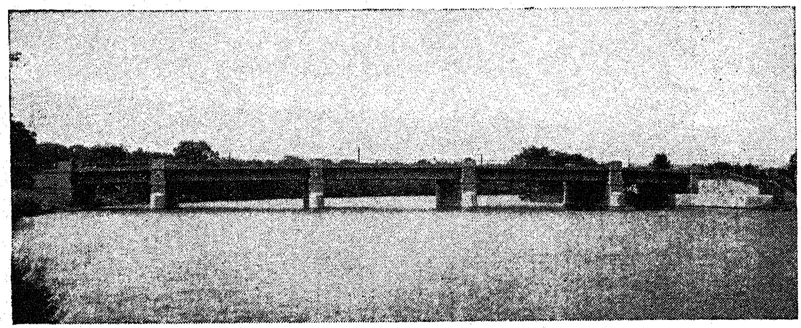


Fig. 1. Riveted bridge, 444 feet long redesigned for arc welding in this study.

In order to meet these conditions and also provide a structure that would not mar the beauty of the surrounding park properties, the new bridge was designed as a five span deck steel plate girder bridge with a roadway 54′–0″ wide and two 11′–0″ sidewalks. The navigation requirements were met by raising the grade and the three center spans were designed as continuous girders to reduce the depth of the bridge. The 13 feet of water in the river and the rock bottom made ideal foundations for this type of design. The highway alignment was improved by putting the superstructure on a skew of 9°–30′ with the center line of the piers. This also enabled the traffic to be handled by the old bridge during the construction of the new. Fig. 1 is a view of the new bridge and shows what a pleasing effect was produced in the finished structure.

But all these peculiarities of the site tended to complicate the problem of the design of the superstructure and meant that every detail had to be carefully analyzed. The roadway was given an asphalt surface on a protection coat of mortar covering the waterproofing fabric over the slab. Details of the actual bridge floor are shown in the half cross section on Fig. 3. The weight of the concrete slab was kept at a minimum by using trussed reinforcing bars arc welded to the tops of the floor beams. This meant that all the steel beams had to be set to accurately follow the grade and crown of the roadway. Each girder had to be cambered for the same purpose and placed at a different elevation on the piers. Combined with the skew of the alignment this involved a multitude of details that made the steelwork hard to fabricate and erect. The arrangement used consisted of steel floor beams set perpendicular to the road about 5′–1½″ apart, framed into five plate girders on 13′–11″ centers, with the concrete sidewalk slab car-

ried on steel brackets and protected by a granite curb and a wrought iron railing.

Navigation required two channels 100′ wide with 20′–0″ clearance above the water and this condition was met by building four piers making five spans, two about 60′–0″ long near either shore and three equal center spans 107′–7½″ long. The girders for the short spans were designed as simple spans. The center span girders were made continuous with the fixed point on the center pier and rocker bearings at the other three supports. Expansion was provided in the roadway by finger castings bolted to skewed I beams at the ends of the girders, and at the sidewalks by checkered plates on steel supports.

Thus, an economical bridge was provided and the plans and specifications drawn for a conventional riveted superstructure. Welding was called for in connecting the fascia angles to the sidewalk beams, fastening the railing posts, the sidewalk end expansion dams and other details, but was not used for any major work except the reinforcing steel for the roadway slab which was shop welded into trussed mats that were arc welded to the tops of the floor beams and girders in the field. The complication of the details was reflected in the fact that the contract drawings consisted of 16 sheets 24″ x 36″ for the superstructure alone and there were 40 sheets of the same size of detail shop drawings. It is not the intention to give the details of the bridge as built in this paper but the essential features can be visualized in the comparison that will be made with the redesign for fabrication by welding.

Studies for Redesign.—In redesigning the superstructure for welding, it was decided that the layout and the general arrangement of the members would be made similar to the riveted design in order to give a direct comparison between the two methods of fabrication. As practically no design data was given in the contract plans, the first step was to check the original design to establish the live loads for the redesign. This showed that both the simple span and continuous girders had been figured by the usual conventional methods and were in accord with the specifications used.

Then a preliminary design was worked out to determine whether it would be economical to figure the girders continuous over five spans keeping the same arrangement of piers and the original depth of girders. In doing this, five cases of live load in different positions on the bridge were figured and plotted and tables of maximum moment and shear made. This scheme was calculated for an all-welded structure and it showed several advantages over the riveted design as follows:

1. A saving of 20% in weight of structural steel for the entire superstructure.
2. A saving of 50% in weight of steel expansion dam castings because the break in the bridge over piers 1 and 4 eliminated the castings at these points.
3. A probable saving in the weight of the cast steel shoes and rockers due to the lighter bridge loads.
4. The bridge would be stiffer longitudinally and therefore have less vibration under live load.

Against these advantages this scheme also had the following disadvantages when compared with the riveted design:

1. The end spans were not economical because of the excessive depth of the girders in relation to the span length which made the web heavier than necessary.
2. The erection in the field would be more difficult on account of the location of the field splices and would therefore require more time and greater expense.
3. This scheme is essentially a different type of bridge and although it would have the same appearance as the riveted design there would not be a direct comparison between the component parts of the structure.

A similar study was then made in which an all-welded bridge was considered using simple span girders for the shore spans and continuous girders for the three equal center spans and making the arrangement of piers, skew, and general parts identical with the riveted design. The advantages of the welded bridge over the riveted one as developed by this study were:

1. A saving of 22½% in weight of the structural steel for the entire bridge.
2. Probable saving in the weight of castings for shoes and rockers.
3. A direct comparison between component parts of the two bridges.
4. Established a basis for accurate weight of steel for the dead load to be applied in the final design.

As the result of these studies the detail design of an all-welded bridge was entered into in accordance with the latter scheme so that any direct savings that were developed could be attributed to the method of welding rather than any changes in major layout.

"Specifications for Steel Highway Bridges" from the Final Report of the Special Committee of the American Society of Civil Engineers as published in Transactions Vol. 87 p. 1275 and revisions, were used for the riveted design. These were adopted for the welded design even though additional savings in weight could have been shown by using later specifications. which permit higher unit stresses. Accordingly the following principal units were used:

ALLOWABLE STRESSES FOR STRUCTURAL STEEL

Tension, net section	16,000 Per Sq. Inch
Bending in extreme fibers of built sections and girders, net section	16,000 Per Sq. Inch
Compression (one Diameter)	16,000 Per Sq. Inch
Shear in plate girder and I beam webs, net section	12,000 Per Sq. Inch

The welding was made to conform to "Specifications for Design, Construction, Alteration and Repair of Highway and Railway Bridges by Fusion Welding" of the American Welding Society.

An attempt was made through the entire design to proportion the members not only for minimum weight within the limits of the per-

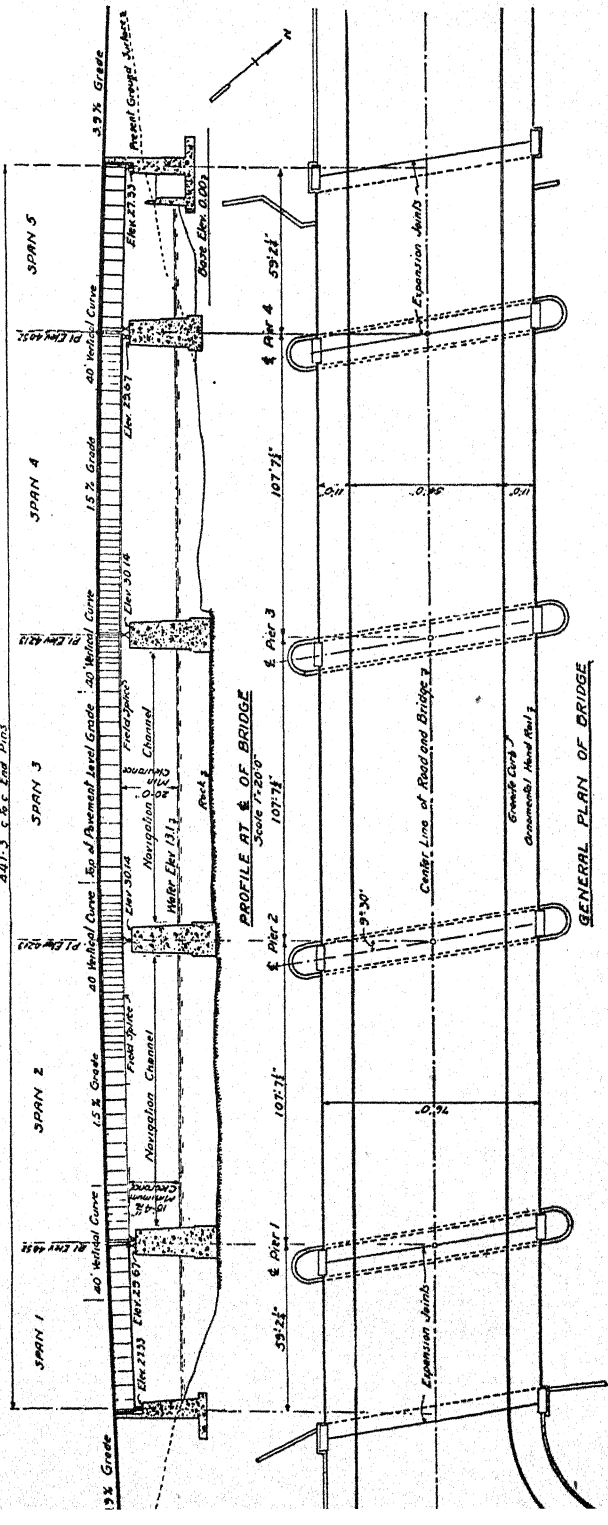


Fig. 2. General plan of bridge and profile at centerline.

missible stresses but also for simplicity of detail, ease of fabrication, minimum welding cost, and speed of erection.

Simplification of Details.—In studying the stresses and applying them to the welded design it was found that the details could be simplified over those used in the original plans and a brief description comparing the two methods will serve to bring out the advantages of the welding method.

The sidewalk bracket design was not changed materially from the riveted design except to use plates instead of angles wherever possible. Typical details of the welded bracket are given on Fig. 3 and comparing data taken from this with the original design we get the following:

ONE SIDEWALK BRACKET

	Riveted	Welded
Total weight	883 lbs.	681 lbs.
Number of pieces	18	13
Number of shop rivets	792	
Number of field rivets	23	
Erection holes and bolts	23	10
Shop welding		1/4" x 26' fillet
		1/2" x 4.5" fillet
Erection welding		1/4" x 4 fillet
		1/2" x 2.5 fillet

The details of the cross bracing and bottom struts were considerably improved in the welding design. The cross braces in the riveted design were all set on the skew and were connected to bent plates by field rivets. A stronger and more direct connection is the split 21" I beam the flange of which is shop welded to the web of the girder. The outstanding web is field welded to the cross brace angles and is only bent where located at the ends of the span on the skew. Although the same angles are used in both designs, the welded scheme eliminates awkward gusset plates and gives a stronger connection. The diagonals and struts bracing the bottom of the girders, were made of two angles 5" x 3½" x ⅜" starred and connected by bent plates to the web of the girders. The 6" H beams used for welding are field welded directly to the bottom flange of the girders and even though they have to be bent slightly to conform to the difference in elevation of the girders, a better brace is afforded.

As the roadway floor beams constitute over one fifth of the total structural steel weight, they were given considerable study. By referring to the final details shown in Fig. 3, it will be noted that the beams are located with the top flange at about the elevation of the top flange of the girder and each beam has to conform to the crown and grade of the roadway. In the original design, the top and bottom flanges were cut at the beam ends and the web was field-riveted to the stiffeners of the continuous girders with seven ⅞" rivets. On the simple spans the connection required additional plates to reinforce the stiffeners and at best the joint did not tend to brace the bridge because

the rivets were in single shear and away from the girder web. In order to improve this and decrease the weight, studies were made of simple and continuous beams. Details of the continuous beams are shown on Fig. 3. In designing this, the maximum live load condition was reduced to an equivalent uniform load and the maximum plus moment taken at .077 times the total load. The maximum negative moment, therefore, was .107 times the total load. The welded connections were designed, however, to develop the entire strength of the beam used. Provision for erection clearance was made as shown and the details in the end spans worked out so that the beams were fixed and, therefore, the same sections could be used. A study was also made of using simple beams which would rest on the stiffener seats as shown in the detail, and would be field welded to 3" x 3" x ⅜" clip angles that had been shop welded to the girder web. At the clearance end of the beam a loose bar 3" x ⅜" would be field welded on one side to make the connection. This scheme had the disadvantage of a possibility of causing undue stress in the welds due to the deflection of the beams under live load and increasing the amount of vertical field welding. A comparison of the three methods is given below:

ONE INTERMEDIATE FLOOR BEAM

	Simple beam Riveted	Simple beam Welded	Continuous beam Welded
Section used	21" WF 59 lbs.	18" WF 57 lbs.	18" WF 47 lbs.
Total wt. per lin. ft.	58.6 lbs.	55.6 lbs.	47.8 lbs.
Number of pieces	3	2	3
Shop rivets	18		
Field rivets	14		
Shop cutting	Top & Bottom	Top Flange	Top Flange
Erection holes	18	4	6
Shop welding		¼"x40" Fillet Clips to girder	
Erection welding		¼"x50" Fillet	½"x27" Fillet ½"x24" Fillet 1⅛"x7" Butt

An estimate showed that there was very little difference in the cost of the welded schemes and in view of this the continuous beam was considered to be the best for the conditions.

In detailing the girders for the end spans, the usual advantage of eliminating a multiplicity of cover plates and fillers and replacing angles by plates was found in the welding design. In order to conform more exactly to the required bending moments, the bottom flange plates were designed to be smooth burned to different widths varying from 14" to 20". The top flange was made a constant width of 18" in order not to complicate the details of the floor system. The interior stiffeners are cut near the top and capped to form a seat connection for the floor beams which are welded to give a positive connection to the girder that was lacking in the riveted design. A comparison of the two methods shows many advantages for the welded girder.

One Girder "F" for Spans 1 and 5

	Riveted	Welded
Total weight	22,644 lbs.	15,435 lbs.
Weight per lin. ft.	377 lbs.	260 lbs.
Number of shop pieces	102	79
Number of shop rivets	1,350	
Shop welding		¼" x 309' Fillet ¾" x 6' Double V Butt ⅜" x 15.5' Single V Butt

The details for the continuous girder are similar. The added advantage is the simplicity of the field splices. These were designed with temporary bolts and splice plates strong enough to take the weight of the steel plus a concentrated moving load from a 75-ton erection traveler. This was done and the splices located so that falsework would be eliminated and the bridge erected and plumbed before the splices were welded. The bottom plates could then be chipped off flush with the bottom flange and the holes in the web and splice plate plug welded. The lap weld of the web splice plate gives additional strength to take care of the residual stress. Comparing this with the riveted splice which required 12 plates and 312 field rivets it is seen to be more compact and efficient. The essential features of the two methods are shown by the following:

One Continuous Girder "C"

	Riveted	Welded
Total weight	182,436 lbs.	114,368 lbs.
Weight per lin. ft.	564 lbs.	350 lbs.
Number of shop pieces	444	415
Number of shop rivets	7,170	
Shop welding		¼" x 2, 109' Fillet Butt Welds at splices
Erection welding		¼" x 23' Fillet ⅜" x 14' Single V Butt 1⅞" x 6' Double V Butt

The simplification of the details was applied to the type of material used in an attempt to keep the number of the sizes of plates and shapes to a minimum. The idea of standardization of pieces was also carried into the different assemblies of parts of the bridge and it was found that even with the complication of skew and grade imposed by the conditions there were numerous instances where slight changes lessened

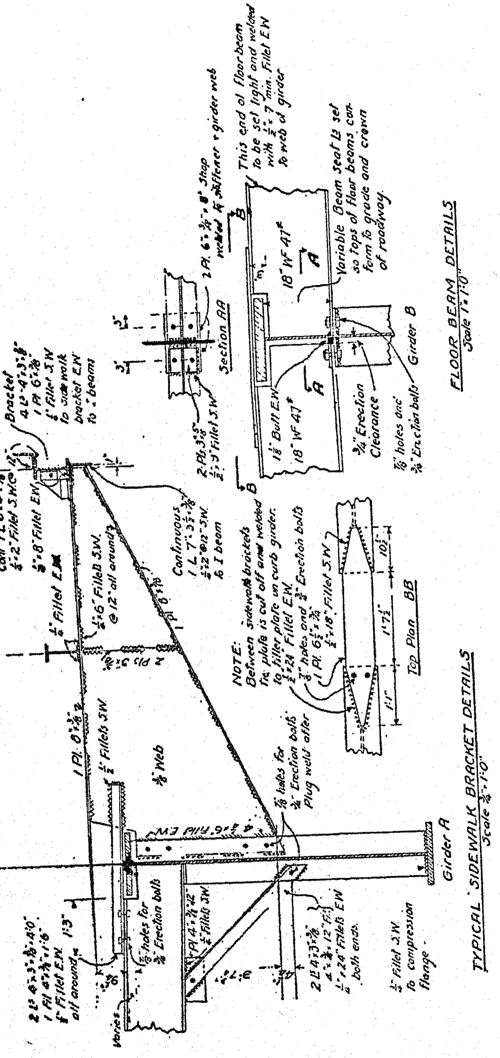


Fig. 3. Cross section details of bridge. **See also page 593b.**

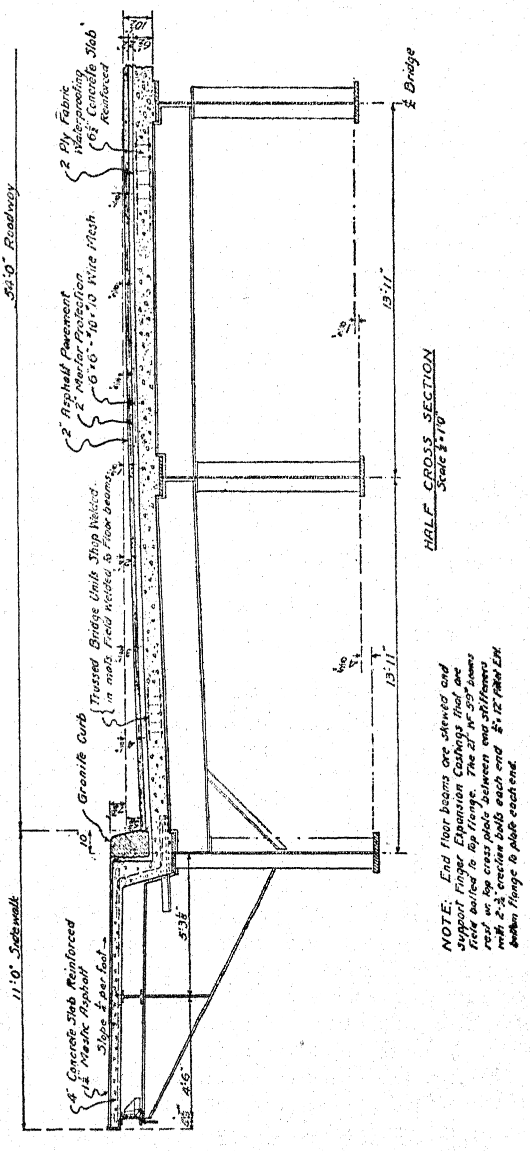


Fig. 3. Cross section details of bridge. See also page 593a.

the multiplicity of peculiar types that only served at one place in the riveted design. These economies, although not very tangible would be reflected in the cost by reducing the number of engineering and shop drawings required and would also make the fabrication and erection less complicated.

Reduction in Weight.—A comparison of the weights of structural steel required by the two methods of fabrication is particularly interesting because it brings out one of the greatest advantages of arc welding as applied to this particular problem. The analysis was made, therefore, in great detail for all parts of the bridge and was assembled so as to give percentages of saving for the separate classes of material involved. The original contract for the steel superstructure provided for the payment of the following items:

No. 1, Anchor bolts with pipe sleeves, bearing pins, in place unit price per pound.

No. 2, Annealed steel castings, including shoes, finger expansion dams, etc., in place, unit price per pound.

No. 3, Roadway expansion dams erected, unit price per lin. ft.

No. 4, Structural steel, erected in place, including all contingent items and operations, unit price per pound.

No. 5, Field painting bridge and railings, lump sum.

The tabulations made for this study include everything paid for as Item No. 4 (structural steel) but exclude the other parts of the structure although the reduction in weight would involve further economies in the shoes, rockers and perhaps the pins.

The structural steel was paid for on the basis of computed weights from the detail shop bills of material which were furnished by the fabricator and checked by the owner's engineer. The bill of finished parts derived from these computed weights was tabulated for the figures given and used for the riveted bridge in this comparison. The weight of the field rivets was included and distributed proportionally.

For the welded structure the weights were computed for each piece from the redesign drawings and additional details worked out in the calculations. In parts that were not changed from the original design a direct comparison was used as a check. The amount of welding metal for each piece was also tabulated and added to the structural steel weights. This amounted to 1.4% of the weight of the steel. As shown in Table I, the results were divided to give a comparison of the simple span bridge, the three-span continuous bridge and the total five-span bridge, with five classes of material distributed as to location and type. In studying this table it must be remembered that some of the savings shown in the percentages are due to improvements of design that cannot be attributed to the use of welding, but an attempt has been made throughout to adhere as nearly as possible to the original arrangement so that the study would be a fair comparison between riveting and welding.

TABLE I—COMPARISON OF WEIGHTS OF STRUCTURAL STEEL

Location	Riveted	Welded	Saved by Welding	Percent of Riveted
ONE SIMPLE SPAN BRIDGE 60 FEET LONG				
Masonry plates	4,750	4,703	47	1.0
Sidewalk	17,211	16,401	810	4.7
Bracing	7,438	5,961	1,477	19.9
Floor beams	43,005	38,325	4,680	10.9
Girders	110,200	77,713	32,487	29.5
TOTAL	182,604 lbs.	143,103 lbs.	39,501 lbs.	21.6
ONE CONTINUOUS THREE SPAN BRIDGE 323 FEET LONG				
Masonry plates	25,033	24,892	141	0.5
Sidewalk	87,788	82,601	5,187	5.9
Bracing	31,054	27,032	4,022	12.9
Floor beams	213,326	175,624	37,702	17.7
Girders	874,681	579,208	295,473	33.7
TOTAL	1,231,882 lbs.	889,357 lbs.	342,525 lbs.	27.7
TOTAL FIVE SPAN BRIDGE 444 FEET LONG				
Masonry plates	34,533	34,298	235	0.7
Sidewalk	122,210	115,403	6,807	5.5
Bracing	45,930	38,954	6,976	15.2
Floor beams	299,335	252,274	47,061	15.7
Girders	1,095,080	734,634	360,446	32.9
TOTAL	1,597,088 lbs.	1,175,563 lbs.	421,525 lbs.	26.4

The first classification of the table, or that of masonry plates, was not changed by the welding as they were not redesigned for the lighter weight and the slight difference is due to the elimination of sidewalk bearing plates on Piers 2 and 3 used in the riveted structure.

The next classification in the table includes the sidewalk stringers, fascia angles, brackets, brace, and the expansion dams at the end of the spans. Except for the bracket and the welded connections, the weights of the individual members were not changed from the original design. However, in the riveted bridge the sidewalk was broken in the continuous span so as to bear on expansion plates on the pylons over Piers 2 and 3. A better arrangement is shown on the redesign by continuing the brackets and making the sidewalk act with the continuity of the girders. This shows little saving in weight but makes a better structure.

The details of the bracing have already been discussed and the saving in weight is due entirely to the use of welding.

The continuity of the floor beams is made economically possible by welding but in the arrangement was changed over Piers 2 and 3 to eliminate skewed beams and connections which were used in the original design.

In the case of the girders the saving in weight is due to the method of fabrication and the figures show a higher percentage of saving for the continuous span than for the simple span. Fig. 4 shows graphically the percent of structural steel saved by arc welding, distributed like the table to compare the different parts of the bridges. The weights and percentages show a decided advantage for arc welding over riveting for these structures.

Analysis of Cost.—A detailed estimate was made of the welding operation to compare with the actual cost of the riveted structure as paid for under the contract. As previously mentioned, the structural steel was bought completely fabricated and erected at a unit price per pound and, therefore, there are no breakdown figures of the details of the riveted method, and the comparison is made only on the final amount.

The estimate of the cost of the completely welded bridge was made in great detail using costs for materials, labor rates, insurance rates and equipment charges that were prevalent in the locality at the time the riveted bridge was produced. There were necessarily a number of assumptions that had to be made as to the operations both in the shop and the field and these were made to conform to average practice rather than confined to one particular layout.

The principal unit prices used are as follows:

Labor Rates

	Per Hour Shop	Field
Structural iron workers	0.85	1.20
Mechanics and operators	0.85	1.20
Riveters and welders	0.85	1.20
Helpers	0.55	0.60
Common labor	0.45	0.55
Watchmen	0.37½	0.37½

Material Prices

Structural Steel at mill	\$1.80 per hundred pounds
Electrode	0.10 per pound
Power	0.02 per KWH
Transportation	0.12 per hundred

A modern shop is assumed in which proper facilities for handling the heavier pieces are available together with sufficient jigs, welding slabs and layout space to take advantage of the duplication of the different types of work.

For instance, there are 348 pieces of 18″ WF beams which require the same amount of cutting, punching and welding. The sidewalk brackets also are similar with 56 pieces required. Such operations as this should be scheduled in the proper sequence and even the smaller pieces such as the diagonal struts and cross bracing can be arranged to be done while the larger pieces are being moved or changed so that a minimum of welding time is lost.

In fabricating the girders, there are several duplicate types of each piece and the splices have been arranged so that convenient units can be handled. The webs will have to be cut to true lines conforming to the grade and camber of the bridge so that good edges are afforded for connection to the cover plates. Then the stiffener plates, and other pieces can be welded to one side with the web in a flat position. The section can then be turned over and the other side completed before being welded to the cover plates. Thus by proper scheduling, practically all the shop welding can be done in a flat position. These operations have been estimated as accurately as possible for this study and the results shown in round figures in Table II.

TABLE II

SUMMARY OF ESTIMATE
OF COST
STRUCTURAL STEEL OF FIVE SPAN GIRDER BRIDGE
DESIGNED FOR ARC WELDING

Material		
Structural steel delivered at mill, including waste		$21,500.00
Shop Work		
Cutting, handling, loading	$4,000.00	
Welding direct operation	2,500.00	
Welding indirect, waste, fatigue, set up, clean	3,000.00	
Shop painting	1,500.00	
Shop operating charges	3,500.00	
		14,500.00
Transportation		2,000.00
Erection		
Erecting bridge	$6,200.00	
Welding direct operation	670.00	
Welding indirect	630.00	
Field supervision	2,500.00	
		10,000.00
TOTAL COST ALL WELDED STEEL		$48,000.00

The cost of welding was estimated by tabulating the different types of welding required for each piece and summarizing them to give the total lineal feet required. For this study it was assumed that the welding was done manually with shielded arc and a unit cost for each type of weld was computed by the methods suggested in the "Procedure Handbook of Arc Welding Design and Practice". The prices and units shown above were used and a machine efficiency of 50% assumed. The kind of weld, total lineal feet required, the unit cost, and the total estimated cost for labor, power, and electrodes as arrived at by this method are given in Table III. This constituted the direct welding cost.

TABLE III—SUMMARY OF DIRECT SHOP WELDING COST

Type of Weld	L.F.	Labor		Power		Electrodes		Total Cost
		Unit	Total	Unit	Total	Unit	Total	
¼" Fillet flat	17,066	0.0425	725.31	0.0114	194.55	0.0370	631.44	1,551.30
½" Fillet flat	1,218	0.0850	103.53	0.0228	27.77	0.0700	85.26	216.56
⅜" Butt	448	0.0606	271.44	0.0120	5.37	0.0580	25.98	302.79
½" Butt	27	0.0940	2.54	0.0450	1.22	0.1400	3.78	7.54
13/16" & ¾" Butt	120	0.1420	17.04	0.5200	62.40	0.1900	22.80	102.24
1⅜" Butt	30	0.3400	10.20	1.7930	53.79	0.3700	11.10	75.09
1⅞" Butt	60	0.4720	28.32	2.9020	174.12	0.4350	26.10	228.54
TOTALS	18,969		1,158.38		519.22		806.46	2,484.06

The indirect cost included such items as operator fatigue, waste of materials and power, and setting up and cleaning of the steel. The cost was computed from an analysis of what was involved for each type of operation and piece handled. Shop painting was estimated on the basis of one coat of red lead called for in the specifications for the riveted structure. Shop operation charges include the items that cannot be charged to the specific job and would vary somewhat for different mills. The rounded out figures for all these items are shown in Table II. Transportation is based on the actual freight rate and the amount is therefore high because actually the steel was brought in to the job by water probably for a special lump sum price which of course is not available.

The estimate of cost for the erection is based on the assumption that the operations were done in the same sequence and with the same equipment except for the welding machines required to replace the riveting tools, as was actually done for the riveted bridge. The steel was all taken directly from barges by a 75-ton traveler with a 90-foot boom which started from the west bank and worked progressively across the different spans by setting the girders on the span ahead. The floor beams and brackets were placed and bolted as the traveler worked out but the diagonals and bracing were placed by hand by the follow up gang. This is also shown on the erection diagram Fig. 5. The riveters started on Span 5 as soon as it was plumbed and adjusted. In the continuous span the riveting gangs had to wait till the traveler moved on to Span 1 so that the bridge could be jacked down to final position after the field splices had been made. As actual figures of rates and man hours were available for the erection of the riveted span, a careful analysis of them was made and the cost of all operations except riveting and building of falsework was segregated. This is shown in the Table II as "Erecting Bridge" and in it no allow-

ance was made for the fact that the welded pieces involved lighter tonnage or that the connections in most cases would be simpler to make.

The direct welding operation was estimated in a similar manner to the shop work, account being taken of the position of the weld. Although all welding possible was designed to be done in a flat position it was inevitable that the web splices and the sidewalk bracket and braces be done in the vertical position. The vertical work amounted to 618 lineal feet or almost 28% of the total 2,459 lineal feet of erection welding required. Table IV shows the costs of the different types

TABLE IV—SUMMARY OF DIRECT ERECTION WELDING COST

Type of Weld	L.F.	Labor		Power		Electrodes		Total Cost
		Unit	Total	Unit	Total	Unit	Total	
¼" Fillet flat	609	0.0600	36.54	0.0114	6.94	0.0370	22.53	66.01
¼" Fillet vertical	608	0.1263	76.79	0.0137	8.33	0.0420	25.54	110.66
½" Fillet flat	905	0.1200	108.60	0.0228	20.63	0.0700	63.35	192.58
⅜" Butt vertical	73	0.1091	7.96	0.0136	1.00	0.0440	3.21	12.17
13/16" Butt flat	15	0.2000	3.00	0.1900	2.85	0.5202	7.80	13.65
1⅛" Butt flat	234	0.4950	115.83	0.0940	22.00	0.3220	75.35	213.18
1⅞" Butt flat	15	0.6670	10.00	2.9020	43.53	0.4350	6.53	60.06
TOTALS	2,459		358.72		105.28		204.31	668.31

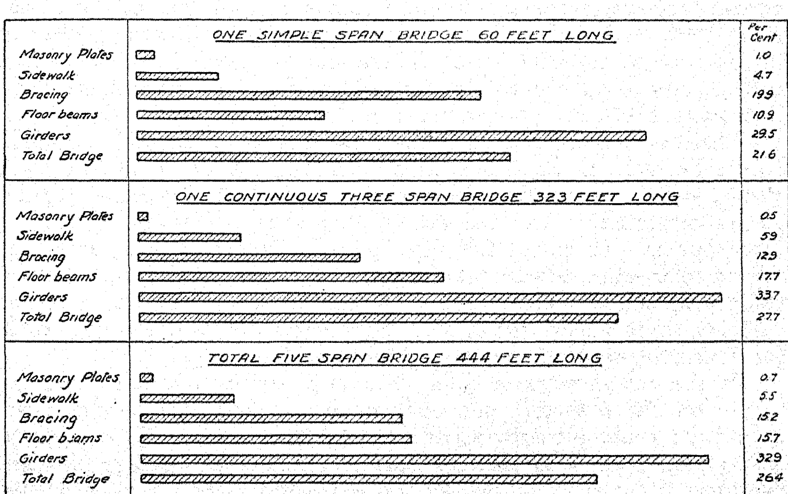


Fig. 4. Percent of riveted structural steel weight saved by arc welding shown graphically.

of welds divided into labor, power and electrodes as was done for the shop fabrication except that the unit rates and prices conform to actual field conditions. The indirect welding cost was also carefully estimated, taking into account the fact that the bolting and locating of the pieces would be done by the erection gang. Field supervision includes equipment and overhead that conforms closely with the actual cost with allowance for the saving of time involved by the method of welding. Field painting is not included because this was done under a separate lump sum and it is assumed that the unit price per pound for the steel would not be affected.

Table II shows the estimated cost of the all welded structural steel superstructure complete in place is $48,000.00 or about 0.041 per pound for the amount of tonnage involved. The comparison in the following table shows that although the unit price per pound is higher for the welded method of fabrication, the saving in weight effected will make an actual saving in cost of about $11,000.00 for the entire bridge.

Comparison of Cost

	Weight	Unit	Amount
Riveted	1,597,088 lbs.	0.037	59,092.25
Welded	1,175,563 lbs.	0.0408	48,000.00
Savings	421,525 lbs.		$11,092.25

Saving by Welding is 18.8% of Riveted Cost.

Erection Speed.—The element of speed of erection was particularly applicable to the actual problem under discussion because due to unforeseen delays in the substructure it was imperative that the superstructure be installed in the minimum time in order for the project to be opened on schedule time. Therefore a careful study was made of the actual field operations to compare with what might have been done with the welded structure.

The design of the riveted continuous girders provided that two field splices be made in Span 3 symmetrically located about 18 feet from Piers 2 and 3 respectively. Under the method of erection elected by the steel company, this involved the construction of falsework near Pier 2 to support one end of the short piece of girder in Span 3 so that the traveler could advance to a point from which the long section comprising the remainder of Span 3 and all of Span 4 could be set. The lift of this $37\frac{1}{2}$ ton girder determined the capacity and reach for which the erection equipment had to be designed.

In the redesign for welding the field splices were arranged as shown on Fig. 5 so that one came in Span 3 and the other in Span 2, and the splice plates were designed so that the bolted connections were strong enough to take the dead load of the steel bridge plus the live load of the traveler moving across the span. This eliminated the need for false work and saved the cost and the time of its construction without imposing any hardship because the total lengths of the girders

before erection were not increased. It was a distinct advantage from a design standpoint because the stresses in the splice were less in the redesigned location as it is nearer the point of zero moment. The change does not make any more complications in erection as in both cases the girders would have to be jacked up to make the splice. A comparison of the two methods is shown by the erection diagram Fig. 5.

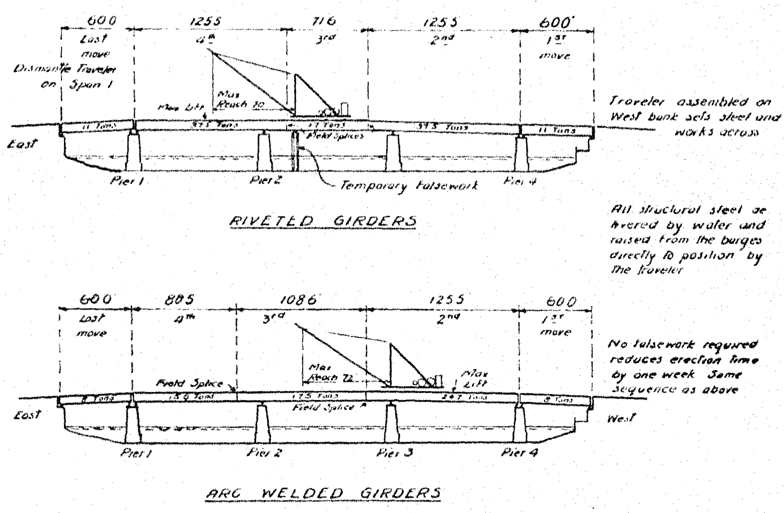


Fig. 5. Erection diagrams.

The field records show that the construction of the falsework required 191 man hours done on 5 working days and its removal about one day. As the falsework could not be erected till the traveler reached the second move and was at Pier 3, the entire operation had to wait while the bents were being made ready for the load of the next girders. This time can reasonably be translated into one calendar week actual time that would be saved by welded erection.

Another item of time saving is shown by a comparison between the actual field riveting time and that estimated for the welding. In the riveted bridge there were 12,690 field rivets which under actual conditions required 975 man hours working from two to three riveting gangs on fourteen days. The operation of making the 2459 lineal feet of erection welding is shown by the analysis to require 300 man hours for direct labor plus 250 man hours for indirect or a total of 550 man hours. Translating this into 8 hour days for twelve welders, the work could be completed in less than six working days. This shows a saving of time in favor of the welding method of eight actual working days or two calendar weeks on the basis of the men being allowed only 30 hours per week which was the actual regulation. However, the riveting and the welding are operations that are coincident to the erection, and, therefore, it is reasonable to assume that one week, or half of the

welding time, would be consumed in waiting for the erection gangs, leaving one week of actual time saved for the total operation.

Combining the saving due to elimination of the falsework and that due to welding time instead of riveting, it is seen that the redesign methods would have shortened the actual erecting time by two weeks or $28\frac{1}{2}\%$ of the total actual erection time. In addition to the expense involved, this saving of time would have promoted the completion of the entire project when every effort was being made to rush the work to finish the bridge for traffic before the winter season.

Conclusion.—In reviewing the comparisons between the fabrication by riveting and welding as brought out by application to this particular problem, there appear to be two things that stand out prominently. First, the solving of any complicated engineering problem can usually be improved by redesign and although this may seem to be pointing out that hindsight is always better than foresight, it is really a plea for careful study and close analysis before a structure is built. The second conclusion as brought out by the study is that arc welding will produce real advantages over riveting for the fabrication of plate-girder bridges.

For this particular case where the arrangement of parts, the stresses used, and the design methods applied, were all made as uniform as possible for both methods, it was found that welding afforded the following advantages:

1. The details of the parts and connections could be simplified and thus make greater uniformity of material used, a reduction of the number of pieces to be handled and more duplication of types of work. This would effect economies not only in the engineering drawings but also in the shop layout, assembly, and fabrication and the erection in the field which would tend to decrease the cost all along the line.
2. By a tabulation of the weight it was shown that welding decreased the weight of one simple 60-foot span bridge by 21.6%, one continuous three span bridge 323 feet long by 27.7% and the total five span-bridge 444 feet long by 26.4% of the actual weight of the riveted bridge as built.
3. Comparing the estimated cost of the all-welded bridge assuming the conditions that pertained for the riveted structure, it was found that a saving of $11,000.00 for the structural steel alone was involved.
4. The erection speed for the welded bridge showed an improvement of $28\frac{1}{2}\%$ of the actual time consumed for the riveted field work.
5. Therefore, a structure of practically identical appearance and equal utility can be produced more economically by arc welding.
6. The use of welding would also enable the use of greater continuity both in the girders and floor system that would tend to make a stiffer and more homogeneous bridge to handle the heavy modern traffic.

In view of the advantages brought out by this study in which two prevalent types of our short-span bridges have been compared, it seems as though the all-welded bridge has a bright future. There are many reasons why there is a broad field for structures of this type:

1. The deck plate girder does away with unsightly overhead obstructions that are objectionable to the motorist from an aesthetic stand point, and which create a greater traffic hazard than the open roadway of the deck type.

2. The bridge lends itself to widening for future traffic conditions by adding girders without disturbing the original installation. This feature is also better accomplished by welding.

3. The modern trend in design is in favor of plate-girder bridges. This is shown by several recent notable instances in which this type has been adopted on spans where truss bridges would have been used in the past.

4. By designing for variable moment of inertia, the straight lines of the bottom flange, thought by some to be unsightly, can be curved economically and the appearance made to meet the modern demand for beauty in our highway bridges.

5. Due to the influence of the depression, the construction of our highways has lagged behind the progress made in the motor industry so that the supply of moderate length bridges adequate for present day traffic is far below the need.

With arc welding to point the way to an economical solution of the problem, a great service will be performed to mankind.

Chapter XI—A Completely Arc Welded Steel Highway Bridge for Secondary Roads

By Stanley G. Reiff,
Secretary and design engineer, General Construction Co., Omaha, Neb.

The problem of bridge economics has ever been one for which there has been no arbitrary solution. While modern theories of structures, particularly structural steel structures, have developed stress calculations and distributions to practically an "exact science" for any particular set of specifications and any definite set of loadings, the problem of the most economical bridge for any special location cannot generally be determined "at a glance."

The American Association of State Highway Officials, our separate state highway departments, and many engineering departments connected with our more metropolitan governmental subdivisions, have done a commendable job in highway bridge design and in establishing standardized plans and specifications. This work is undoubtedly playing a big part in the development of a finer and safer federal and state highway system and no sensible citizen could criticize these organizations for spending large sums of money for these improvements. The fact that a great deal of the expense of these modern structures is incurred because their design is predicated on carefully worked-out probable future traffic speeds, densities, and loadings and that aesthetic effects are being considered to a much greater degree than ever before, should be a cause for public appreciation rather than criticism.

But there is another problem of bridge economics which has not, we believe, been given all the detailed consideration it deserves. This is the problem of small secondary and less important bridges on the roads, which are not hard surfaced and will not be for many years to come, that serve our rural communities and which, in the great agricultural region, will continue to serve only local traffic and will never be subject to extreme loadings, excessive traffic densities, or high speeds. It is these short span bridges, (See Fig. 1) serving the millions of individuals and thousands of small communities in the great flat and gently rolling middle states, with which this paper has to deal.

Within the last few years, the ever increasing relief load that has been saddled onto the local political subdivisions, plus the rapid decline in property valuations, has reduced the tax funds available for these structures to a place where the greatest economy is necessary. And, in the face of this "forced economy," these village officials, county commissioners and supervisors, etc., have been required to continue to try to maintain and improve their respective highway systems and drainage structures. In most cases, when these officials are faced with the problem of replacing a particular bridge, they have two alternatives. First they can replace it temporarily with a wooden structure like the one which has just proved its insufficiency by having rotted-out, worn out, burned out, or become obsolete because of being too light

to carry modern highway loads. This is probably in most cases the cheapest solution for the moment but it is, at best, only a temporary solution of the problem and in the long run it will be an expensive solution. If they desire to exercise their other choice and build a permanent structure, they can either resort to some out-of-date state standard plans which are reasonably inexpensive to build because they were designed for only the lightest of motor truck and tractor loads, or else they can adopt some present state standard which is satisfactory in every respect except that it is heavier than they require, it is much more beautiful than the location justifies, and it is far more expensive than they can afford to build.

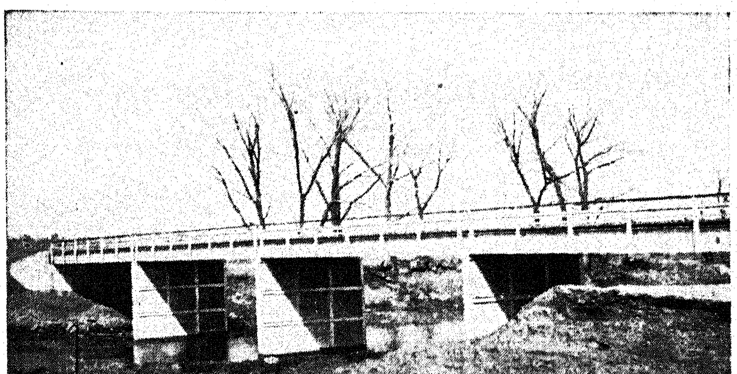


Fig. 1. Completely arc welded highway bridge, four 50-foot spans, 20-foot roadway.

Our problem, as contractors, resolved itself into trying to fill this need by designing a type of bridge that could be built economically in single simple spans from 30′ to 60′, or in multiples of these simple spans, and up to 20′ clear roadway which for this type structure is wide enough. The factors we felt we had to consider in the design, in their order of relative importance, were: (1), ample strength; (2), economy; (3), simplicity; (4), permanence; (5), minimum maintenance; and, (6), beauty. Of course, these items are all more or less inter-dependent.

The idea occurred to us that the solution to this problem was to design a bridge that could be built economically from structural steel, for strength and permanence, the members of which could be cut to length at the steel mill, shipped directly to the job site, and all connections made in the field by arc welding for simplicity and economy. The obvious economy of this plan would be complete elimination of any shop fabrication and extra handling costs and of any middleman profits. Any extra economies that could be realized through savings of material on account of the welded design would be welcome. The limiting factor in the design would be that it would have to allow for mill tolerances in the cutting-to-length of the members because a great deal of the economy would be lost if the "extras" for mill cutting to "exact length" or for "milling" had to be absorbed.

The substructure for the bridge was immediately decided upon as steel piling. Such substructures have been used in this part of the country for many years, have proven very satisfactory, and have been accepted by the highest engineering authorities. The number, length, section, and spacing of these piling are problems which must be settled by local conditions. The steel caps and the necessary bracing for the substructure could be easily and economically arc welded to the piling after driving.

There is a special economy here in the use of arc welding because on either bolted or riveted work using steel piling, the steel piling have to be field punched or drilled so that the holes will satisfactorily match the holes in the shop-fabricated caps and bracing because it is impossible to determine ahead of actual driving the exact elevation to which the piling will have to be driven to develop the required bearing resistance. This is an expensive process regardless of how it is done.

After much deliberation, we chose the three-panel deck girder as the type of superstructure best adapted to our problem. This consists of two main girders with transverse floorbeams at the ends and third-points and steel stringers between and parallel to the girders. (See sketch Fig. 2). It was decided to use connecting angles to connect the floorbeams to the girder webs similar to riveted connections but smaller leg dimensions so as to be able to allow for probable discrepancies in the lengths of the floorbeams when cut to mill tolerance ($\frac{3}{8}''$ over or under). The stringers could similarly be framed into the floorbeam webs, but it made for simplicity and considerable saving to set them on top of the top flanges of the floorbeams.

Reinforced concrete was considered for the floor and it, of course, filled the requirements of permanence and minimum maintenance perfectly but it was decided against because of its high original cost and excessive weight.

Open steel flooring was considered, and fitted into the welded design beautifully, but had to be discarded because of the high original cost and possible impracticality of the open steel floor in rural districts where livestock would have to cross often.

The type of floor finally selected was a laminated floor of either creosoted yellow pine or untreated redwood. A wearing surface of either asphalt mastic or asphalt plank, or just a clay and gravel mixture could be applied economically to this type of floor to give it an all-weather surface and keep the floor from being damaged by the lugs on steel wheeled farm tractors, and it would have a reasonable life-expectancy of 20 to 25 years which was considered ample.

After careful consideration had been given to more conventional types, the laterals were designed as flat bars to be welded onto the tops of the bottom flanges of the floorbeams so that no connection plates would be necessary. They could be pre-stressed by heating and shrinking so as to eliminate the necessity and expense of turnbuckles.

The handrail posts were decided on as either angles which are cheaper or 4" H-beams which are more symmetrical. In either case, they could be attached to the girder flanges by clip angles. This would make for an extremely rigid handrail post and the type of connection to the

girders would provide for such adjustment as might be necessary for perfect alignment of the railing.

In designing the welded connections, every effort was made to specify downhand welding wherever possible and the result was that for a typical bridge of this design there is from 65% to 75% downhand welding, from 25% to 35% vertical welding, and only from 1% to 2% overhead welding. All of the connections were laid out for fillet welding from 1/4" fillet to 1/2" fillet except where it might be necessary to splice the steel piling which involves some butt welding. Fillet welds were easily seen to be the most desirable type because of their simplicity, but the main reason why they were preferred was that in using them it would be possible to eliminate the necessity for any expensive beveling of edges prior to welding. Practically all of the welding was so laid out as to be in shear and no tension welds were used.

It seems trite to include the statement that this type of structure could never have been conceived except for the recent developments of the shielded arc process of welding. All of the welding was laid out to be done with heavily coated rod.

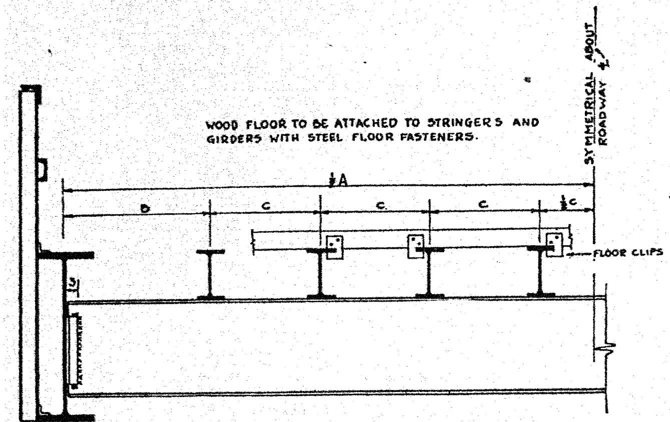
When we had gone this far with the design, we were convinced that we had something that was worthwhile but we could not be sure of the way it was going to appeal to our customers because of the fact that there was no precedent in this part of the country for a completely welded bridge, and only scattered examples of bridges that contained any welding at all. We were also a little uncertain as to just what the actual field welding would cost and could not determine just how much more or less the general erection would cost than for similar bolted or riveted work. The result was that we took our first job more or less "in the dark." We learned a great deal on that first job, but the main thing we learned was that we had a type of bridge that could be built economically and quickly and one that appealed to everyone who saw it. The idea was a success.

Because of the fact that the steel for these bridges was not to go through a fabricating shop, it was necessary to so lay out the erection that satisfactory connections could be made and perfect alignment of all parts could be maintained, during and after erection, without the use of any erection bolts. For this reason, the erection of the bridge required more ingenuity and study than the actual design.

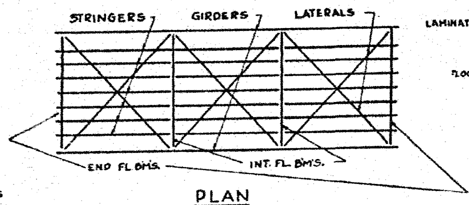
Because this all-welded bridge was such an innovation in this part of the country, at least, and because we were pioneering the proposition, we did not spare any expense in obtaining the best structural welders available. Exhaustive tests were made to determine the prospective operator's ability and none was allowed to weld on the job that did not prove that he could consistently produce first-class work. The welding machines used have been, in all cases, portable gasoline engine driven 40-volt generators developing 300-400 amperes.

The driving of the steel piling presents no unusual problem. It is driven to the required bearing capacity with either a drop hammer or a steam hammer.

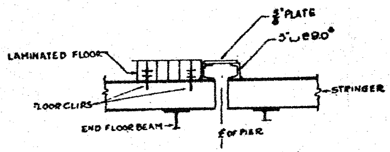
A particular advantage to having an arc welding machine on the job when driving steel piling is that it makes it possible to easily and quickly splice the piling in case the subsoil is softer than anticipated



SECTION THRU ROADWAY



PLAN



FLOOR EXPANSION

FOR MULTIPLE SPAN BRIDGES

	Principal Dimensions				
Roadway	16'	18'	20'		
A*	15'-4⅝	17'-3⅜	19'-3⅝		
B*	2'-8 9/16	2'-7 13/16	2'-7 13/16		
C	5 Spaces @ 2'-0	6 Spaces @ 2'-0	7 Spaces @ 2'-0		
Span	40'	45'	50'	55'	60'
D	12'-8	14'-4	16'-0	17'-8	19'-4
E	1'-0½	1'-0	1'-0	1'-0½	1'-0⅛
F	5'-5	5'-4½	5'-4	5'-3½	5'-3¼

* SHOWN FOR 50' SPAN - FOR ANY SPAN A = RDWY + 5¼" - WIDTH OF GIRDER FLANGE. B = ½(A - ΣC)

	16 ft. Roadway				
	40' Span	45' Span	50' Span	55' Span	60' Span
Girders	27"×91#	27"×98#	30"×108#	30"×108#	33"×125#
End Fl. Bm's.	16"×36#	16"×36#	16"×36#	16"×36#	16"×40#
Int. Fl. Bm's.	16"×36#	16"×36#	16"×40#	16"×40#	16"×40#
Stringers	8"×17#	8"×19#	10"×21#	12"×25#	12"×25#
Length of Floor Beam Connection Angles — End	12"	12"	12"	13"	13"
Length of Floor Beam Connection Angles — Int.	12"	12"	13"	13"	13"

	18 ft. Roadway				
	40' Span	45' Span	50' Span	55' Span	60' Span
Girders	27"×98#	30"×108#	33"×125#	33"×132#	36"×150#
End Fl. Bm's.	18"×50#	18"×50#	18"×55#	18"×55#	18"×55#
Int. Fl. Bm's.	18"×55#	18"×55#	18"×64#	21"×59#	21"×59#
Stringers	8"×17#	8"×19#	10"×21#	12"×25#	12"×25#
Length of Floor Beam Connection Angles — End	15"	15"	15"	15"	15"
Length of Floor Beam Connection Angles — Int.	15"	15"	15"	16"	16"

	20 ft. Roadway				
	40' Span	45' Span	50' Span	55' Span	60' Span
Girders	27"×98#	30"×108#	33"×125#	33"×141#	36"×150#
End Fl. Bm's.	18"×64#	18"×64#	21"×59#	21"×59#	21"×59#
Int. Fl. Bm's.	18"×64#	18"×70#	21"×63#	21"×63#	21"×63#
Stringers	8"×17#	8"×19#	10"×21#	12"×25#	12"×25#
Length of Floor Beam Connection Angles — End	16"	16"	16"	16"	16"
Length of Floor Beam Connection Angles — Int.	16"	17"	17"	17"	17"

Fig. 2. Design of superstructure and steel railing for arc welded three-panel deck steel girders. See also page 607b.

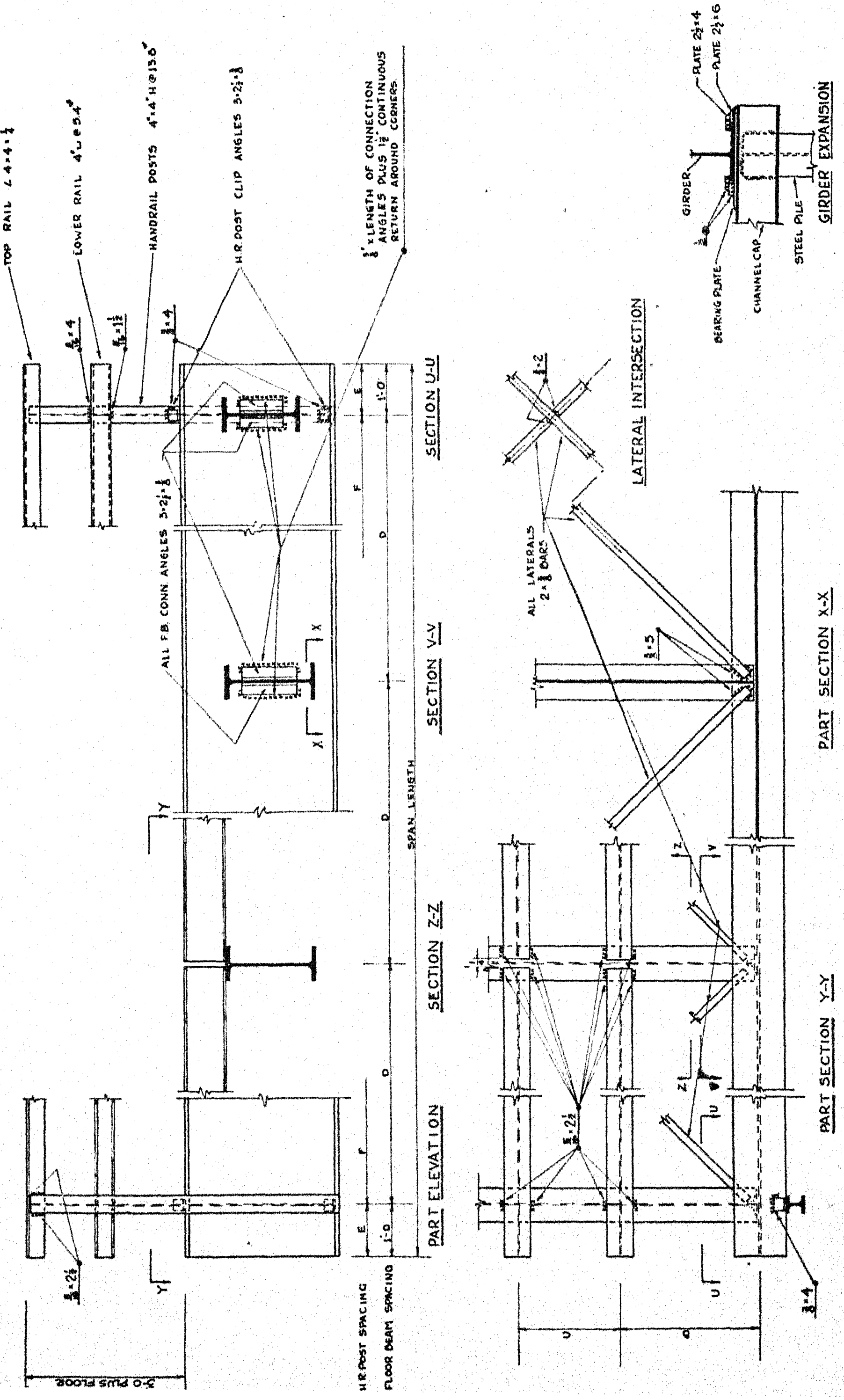


Fig. 2. Design of superstructure and steel railing for arc welded three-panel deck steel girders. **See also page 607a.**

and it becomes necessary to increase the length of the piling to get the required bearing. Or, if the required length of piling is so great as to make it unwieldy, it can be driven in sections and full strength splices developed economically by arc welding. After the piling are driven to the required penetration and have developed the required resistance, they are cut off to the proper grade with an oxy-acetylene torch. Steel channels are used for both caps and bracing on the piling. They are clamped into place with heavy screw clamps and welded to the piling. See Fig. 3 for typical examples of substructure framing.

Fig. 3. Substructure framing during erection.

When the abutments are to be encased in concrete, no structural bracing is required except the caps and wing sash but when they are to have treated lumber backing and wings the piling is X-braced with steel channels. When piers are open they are likewise X-braced for lateral strength. When a concrete web is to be used in the piers, the X-bracing is omitted and horizontal steel channel sash are welded onto the piling, at equal vertical intervals to make the form work interchangeable, and short steel bars are welded across the sash between the piling to make the steel and concrete more nearly an integral unit. Ice breakers made up of extra piling, steel channel sash and cap, and a nose angle may be incorporated when local conditions demand or a single vertical nose angle may be welded to the upstream piling (See Fig. 4). It is easily seen how simple these details are for welded

construction and how much more complicated and expensive they would be for bolted or riveted work.

In the erection of the superstructure, the girders are first set in place and the fixed ends welded down to the bearing plates on the caps. The expansion end is held in place by small keeper plates and allowed to slide on the bearing plate.

The floorbeam connection angles are welded to the floorbeams prior to their erection. It was found advantageous to make a template for this in order to insure the angles being square with the beams and the overall finished length of the beams being exact. By welding the angles on one side with the beam lying flat and then turning the beam over, all this welding can be done in the downhand position. The floorbeams are then put in place between the girders and blocked up on the bottom flanges of the girders to their proper elevations. The girder webs are pulled in against the floorbeam connection angles with chains and chain tighteners and the welding is done. The stringers are placed on top of the floorbeams, spaced with a template and welded into place with downhand fillet welds.

With the girders, floorbeams, and stringers in place, the span is checked to see that it lines up between the ends. If it is out of line any place due to the girders not being perfectly straight, it is pulled into line with cables and turnbuckles and held there while the laterals are installed. The flat bars used for laterals are put in place one at a time, being supported for practically their entire length on wooden templates hung from the stringers. This keeps them from sagging. One end of the lateral is then welded down to the top of the bottom flange of the floorbeam. Next, a section of the lateral is heated with an oxy-acetylene heating torch until the loose end has moved enough to indicate about $\frac{1}{8}''$ elongation of the bar. While the lateral is hot, the loose end is welded down. Then the heated section is cooled and the contraction of the metal in cooling causes the lateral to be pre-stressed and tight. The templates can then be removed and used on the next lateral. When the two laterals in a panel have been thus installed, they are welded together at the center where they cross to keep them from rattling.

When all the laterals have been installed, the handrail posts are erected. The lower clip angles are welded onto the posts in the yard before erection. It is not satisfactory to weld the upper clip angles onto the posts at this time because of slight variations in the depth of the girders. The upper clip angles are welded in place to transit line on the top flange of the girders, care being taken to establish this line slightly outside of the outside edge of the girder flange so that any local irregularities in the rolling of the girders will not interfere with subsequent plumbing of the posts. The posts are then set in place, with the lower clip angle resting on the top of the bottom flange of the girder. They are plumbed sideways and the upper clip angle is welded to the post. With all the posts erected, and the lower clip angles still unwelded to the lower flanges of the girders, the railing is put up.

The top rail angle is clamped in place on the posts, using small thumb screw clamps. It is clamped to the posts at the ends of the span at the specified distance above the top flange of the girder and

is cambered between the ends of the span to offset the deflection of the span under the completed dead load. The necessary camber at the intermediate posts can be taken from a "deflection curve due to floor load" and with a surveyor's level the correct elevations can easily be established at each post and the top rail clamped on these posts to fit this curve. The top rail is then welded in place to the posts. The lower rail is spaced at the proper distance below the upper rail with a spacing template, clamped and welded in place. After all the railing is in place, it is lined up from end to end by moving the posts in or out as necessary and, when it is all in line, by welding the lower clip angles to the bottom flanges of the girders. This method of erecting the handrail makes possible getting it in perfect alignment and to perfect grade and with a little experience the work can be done very rapidly. One welder and four men have erected, lined, welded and completed over 1000′ of this type handrail (See Fig. 5), in three 8-hour days.

The floor expansion for the bridge is made up as shown in the sketch, Fig. 2, from two ship channels and a plate.

The laminated floor is fastened to the stringers and girders with patented floor clips and double pointed nails. This floor fastener is beautifully adapted to this particular design because it is unnecessary to have the stringers punched for any floor fasteners and the floor clips serve the extra function of providing lateral support to the compression flanges of the stringers.

In some of our most recent jobs of this type, we have eliminated the end floorbeams and extended the substructure and caps up between the girders to carry the end panels of stringers. This is a very simple change for arc welded field fabrication and produces a slight extra economy.

We have found that for skew bridges, a variation of our original design can be used to great advantage and to further extra economy because the welding details remain simple regardless of the angle of skew while the shop fabrication of skew bridges becomes very complicated and expensive.

We had one very interesting case in which a 60′ span of the type of the original design was ordered and delivered to be erected as a square-ended structure but some right-of-way difficulties prevented its being erected at the anticipated site and it had to be moved to another site just a mile away on the same stream where the same length span was satisfactory but it had to be a 45° skew to fit. With only a small amount of field cutting, and the furnishing of a few hundred pounds of extra metal, the structure was erected as a skew bridge. Of course this is a very unusual case but it illustrates the flexibility of the proposition and in this case made possible a perfect job where any kind of a job at all would have been impossible if the original order had been for a bolted or riveted structure.

Prior to our erection of the first job of this type, some of our unenthusiastic colleagues maintained that, since all the welding would have to be done in the field and therefore under probably unfavorable conditions as to accurate fabrication, limited handling equipment, and weather, we could not hope to get a satisfactory job. However, we were

not to be discouraged and spent a great deal of time and thought in anticipating possible difficulties and providing for every contingency we could foresee. The rest we had to leave to careful supervision and close inspection of the work during erection. The extreme care with

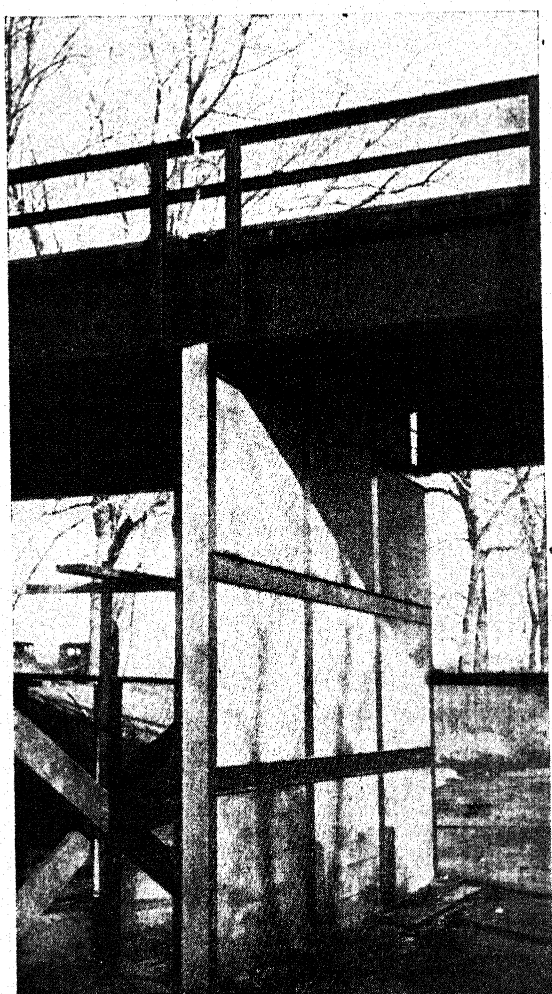


Fig. 4. Single vertical nose angle arc welded to up-stream piling.

which these jobs have been erected is, we feel, completely justified by the very satisfactory results we have obtained. A very recent and thorough inspection, of all the jobs we have built, has failed to disclose a single cracked weld or a single evidence that any future weakness might develop; and this is in the face of the fact that the first of the

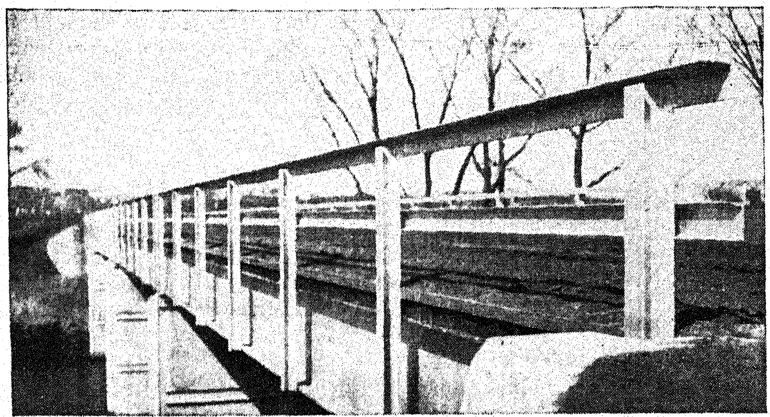


Fig. 5. View of bridge showing railing and supports.

bridges has successfully carried some loads of special heavy construction equipment that greatly exceeded its design loads.

Since one of the principal reasons for designing this type of structure was to develop an economical bridge, its ultimate economy is of the greatest interest. This economy can be well illustrated by the comparative figures for a structure we actually built.

Weight of necessary steel for conventional shop fabricated bridge (shop riveted and field bolted)		438,684 lbs.
Weight of necessary steel for welded bridge of same dimensions and capacity (actually built)		419,560 lbs.
Actual saving in metal (4.4%)		19,124 lbs.
Cost of conventional bridge steel FOB destination		$14,376.94
Cost of steel for welded bridge FOB destination		$11,036.13
Saving in cost of material (23.23%)		$ 3,340.81
Carefully estimated cost of erecting conventional bridge based on actual experience		$ 5,775.00
Actual cost of erecting welded bridge (exclusive of welding cost)	$5,161.18	
Actual cost of welding including operators, rod, insurance, equipment, etc.	$1,256.91	
Total cost of erecting welded bridge		$ 6,418.09
Thus the total cost of the completed riveted and bolted bridge would have been		$20,151.94
Actual cost of completed welded bridge was		$17,454.22
Actual net saving on this project (13.3%)		$ 2,697.72

This saving, which might have been considered small in the days of good times and large profits, represents a very worthwhile economy in these depression and recession-ridden times and coupled with the fact that the customer can obtain in the welded structure a bridge that is equally permanent and strong, more rigid, more beautiful, and subject to less future maintenance than its conventional counterpart, it is convincing.

The acceptability of this design and of the finished structures is evidenced by the fact that in the short time since the idea was conceived, we have sold and erected almost 3000 lineal feet of this type of bridge involving over 2,000,000 pounds of structural steel that has enjoyed the unique experience of never having seen a fabricating shop, never having its full strength reduced by being punched full of holes, and never being subject to the nerve-racking clatter of a riveting hammer. These bridges stand today, happily and safely serving their public, smugly radiant in their smooth sleek appearance, permanently rattle-proof, proudly defiant of the ravages of time and high-water, and convinced that their original economy will be confirmed and magnified by years of service at minimum maintenance—monuments to the art and science of arc welding.

Chapter XII—All Arc Welded Steel Railway Trestle

By Thomas H. Gardner,
Structural engineer, Florida East Coast Railway, St. Augustine, Fla.

The Florida East Coast Railway is fabricating and having erected at this time* an all-steel railway trestle for main line use. (See Fig. 1). This structure is believed the first of its kind.

It is unique not only in being the first of its type but in its fabrication as well. The fabrication is being done at the site of the new bridge by railway forces.

An all-welded temporary fabricating shed and plant was built and erected solely for the construction of this bridge. This work was also done by the railway forces. The work is going on using new equipment. Air hammers, forges and shears are missing. The economical use of structural arc welding is again proving a great saving in railway bridge construction.

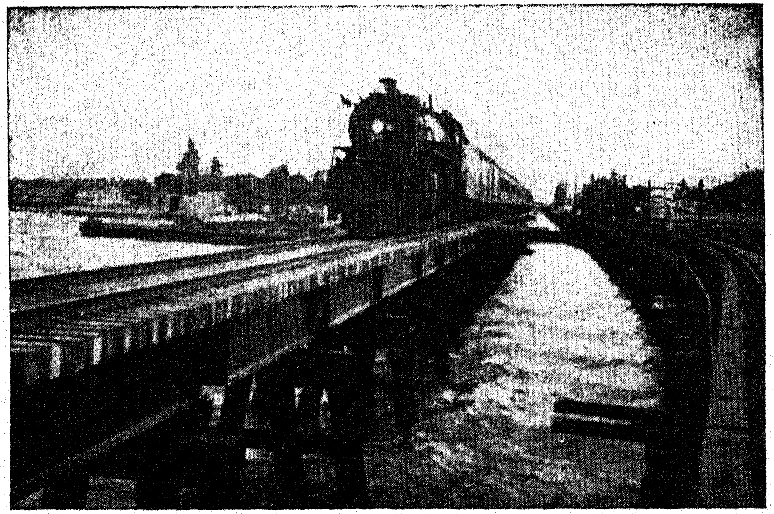


Fig. 1. Express train crossing arc welded trestle. Photo taken at time structure was placed in use—September, 1938. This photo was not a part of the original paper.

This step taken by the railway is the result of the uniformly excellent results obtained in the past. Preceding this work they have built and used, on their main line, all welded steel railway spans, both fixed and movable.

They have put in all welded one-ply steel stringers and caps for trestle work. This work, which now is pioneering in this country, is proving economical not only in the first cost but in maintenance.

*At time paper was written.

General.—The Florida East Coast Railway main tracks cross the St. Lucie River on a bridge at Stuart, Florida, the famous fishing resort.

Previous to 1925 this structure consisted of single-track approaches connecting with a swing drawbridge. The approaches were 70′ deck girder spans on concrete piers encased in steel cylinders.

In 1925, the railway constructed a double-track bascule span, replacing the old swing span, and also constructed a temporary run around pile trestle which connected to the south bound track of the new bascule. This structure, 1300 feet long, runs approximately north and south. Traffic at that time was diverted to the temporary trestle. It was the intention then to build new double track approaches, using 70 ft. deck girder spans carried on concrete piers. The construction of the approach was deferred for financial reasons.

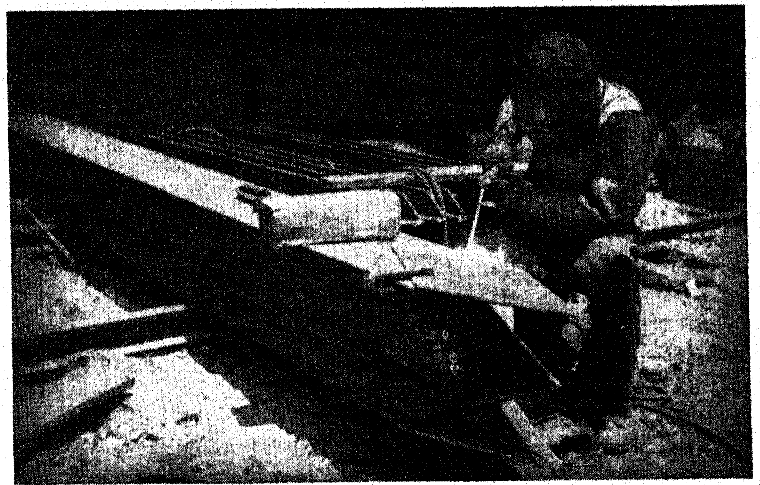


Fig. 2. Arc welding splice for piling.

Study of Design.—Since 1925, considerable study has been given to tentative designs for the approaches to the double-track bascule. It was considered that a more economical type of permanent construction could be developed than the design originally contemplated. Among the considerations for the superstructure were reinforced concrete slabs, rolled beams, built up deck girders and trusses. For the substructure, concrete piers on bearing piles, steel casings filled with concrete and supported on bearing piles, concrete piers on spread footings, and steel bearing piles were considered.

After study of various combinations it developed that an arc welded steel trestle was the most economical type of permanent construction. This was adopted predicated on single-track operation for the present, with possible future double track.

Foundation Condition a Problem.—The St. Lucie River, which this structure crosses, empties into the Atlantic Ocean about five miles

distant. There is an average tide of approximately one foot, the water being more or less salt. Borings taken by others than the railway of the river bed near this location showed sand, shell, and gumbo in various proportions. A strata of soft rock of questionable thickness and questionable bearing value was indicated at an elevation of about minus 60 feet. The maximum water depth at the crossing is about 25 feet. There is also considerable silt of varying thickness lying on the river bed, having been brought in by the drainage canal emptying into the river.

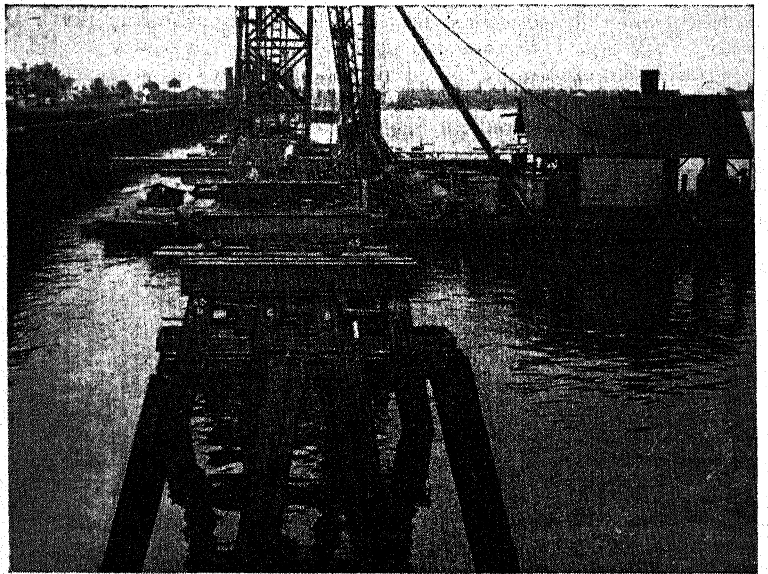


Fig. 3. Bents consisting of four piles each.

Test Piles Driven.—The design maximum load on the piles is 90 tons. Twelve 14" x 14½" x 89" bearing piles were ordered in lengths from 70 to 80 feet. It was decided to drive several test piles in the proper location and later incorporate these test piles in the new bridge instead of driving and pulling the test piles. This was done. The first two piles driven were plain piles 80 feet long. These were driven, spliced in the manner shown in Fig. 2 and driven to a depth of minus 100 feet and minus 108 feet respectively. The value of the soft rock existing in the river bottom did not show up in the driving records. Timber lagging was then put on the piles for a distance of about twenty feet from the tip end. Six of these lagged piles were driven to the required bearing. These piles went to an elevation of between minus 42 feet and minus 59 feet. The lagging will be described later.

Design Features.—The design adopted after considerable study and investigation was to use alternate continuous and simple spans carried on bents of 4 piles each, (See Fig. 3). All piles were battered. The webs of the piles were parallel to the longitudinal center line of the track. This design was carried out except in a special case for the

bents just north and south of the bascule span. These bents were 3 pile bents, all plumb. These two bents were assumed to have no lateral rigidity, the lateral forces being assumed to be carried to the adjacent bent and to the piers of the bascule. A shallow, short simple span was used at both ends. This was to reduce the depth of the span and the attendant reduction in the height of the back wall. The south approach is approximately 800 feet long and the north approach is approximately 400 feet in length.

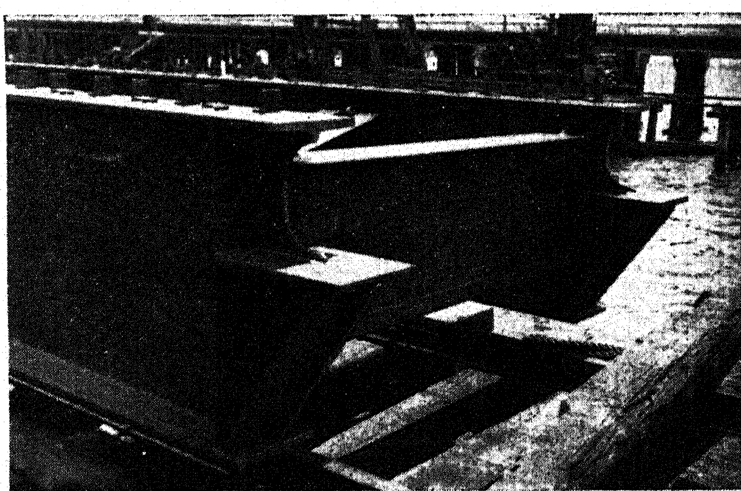


Fig. 4. Ends of three-span girders with supporting bracket which cantilevers out 1' 3".

Three Span Continuous Beams.—The continuous spans developed were three-span continuous. The bent spacing was 23'6", 30'0" and 23'6". This ratio provided approximately the least maximum bending moment, with a fair proportion of bent reactions. The reaction on the interior bents being approximately one third more than on the end bents. The bent spacings at the simple span which alternates with the continuous beams were 28'0". The ends of the three-span continuous girders have a supporting bracket which cantilever out 1'3" beyond bents. (See Fig. 4). This cantilever bracket carries the reaction of the simple spans and reduces the effective length of the simple span from 28'-0" to 25'6". The design loading is Coopers E 60. One ply 36" wide flange beams at 160 lbs. were used for the continuous girders. The same section was used for the simple span, but cover plates, part length, were required top and bottom.

Solid Cross Frames.—Instead of the conventional built-up cross frames, the cross frames at the bents were a 21", 59 lbs. wide flange beams. The cross frames were squared off at the ends, and connected directly to the webs of the 36" beams. (See Fig. 5). The intermediate cross frames were 10" 49 lbs. wide flange beams with a bracket of the same section stiffening the bottom chord.

The 21" cross frames were spaced five inches below the top of the 36" beam and ten inches above the bottom. Diaphragms were inserted top and bottom to serve as stiffeners to the chords. The top of the cross frames determined the horizontal plane of the top lateral bracing.

Split Beams for Laterals.—Four-inch and five-inch Tees split from 8-inch and 10-inch standard beams were used for the laterals. Both the flange and the stem of the laterals were tapered off at the ends reducing the section to practically a point. This avoids the high stress concentration attendant with a square-end section. The top lateral gussets are a Tee section 4" x 14½" with a stem four inches high. The stem welds to the under side of the top chords. These lateral connection Tees were cut from the 14" pile cut-offs, effecting a saving of material.

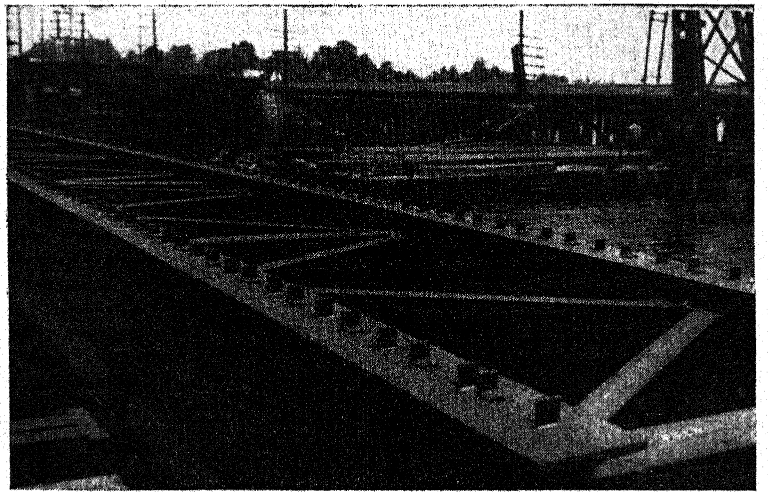


Fig. 5. Details of 80-foot continuous girder.

Simple Spans.—The simple spans are shallowed up at the ends by removing a section of the web, bending up the bottom flange and welding to the web. The web is reinforced in the shallow part by side plates welded on either side. As mentioned before, the end reaction of the simple spans is carried on the cantilever seat on the ends of the 80-ft. continuous girders.

This design involved additional fabrication costs on the simple spans, but brought about the following advantages:

(a) It reduced the effective length of the span nine per cent with the attendant greater reduction in weight.

(b) It avoided the use of the two sets of pedestals on the end bents with the attendant saving and reduced the eccentric loading which would have been imposed.

(c) It allowed ease of correction in the length of the simple spans in the field to take care of the inaccuracy in driving the piles.

(The ends of these spans have two sets of stiffeners either of which may carry the load).

(d) It provided accessible details which can easily be maintained and inspected.

End Cross Frames Moved.—The end cross frames of the simple spans are located approximately three feet from the end of the spans at the point where the bottom flanges are bent up. A stiffener is placed on the outside of the webs.

This detail avoids buckling of the web at the change in direction of the bottom flange.

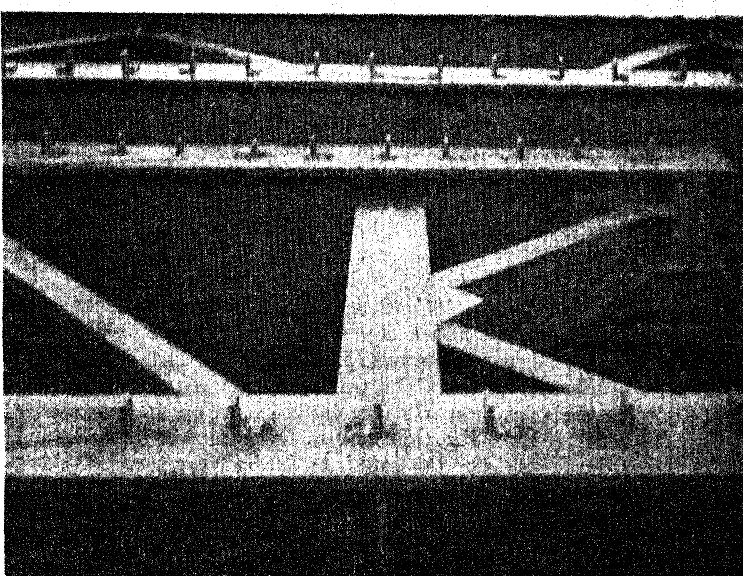


Fig. 6. Two lateral tees, from end cross frames to the end stiffener in the simple span, form a K-frame.

"K" Frame in Ends.—From the end cross frames in the simple span to the end stiffener two lateral Tees are applied forming a "K" frame. (See Fig. 6). This avoids having two cross frames in adjacent spans together. A bridge tie over the "K" frame near the bent will be made with a removable section, enabling access through the deck down to the cap. The pedestals are 15″ in height with the cross frame being 10″ above the bottom chords. Thus, a space of more than two feet will be provided between the cap and the adjacent cross frame which will allow accessibility.

Anchor Bolts Omitted.—The continuous girders are held down by large washers secured by bolts. The lateral movement is restrained by stops on the pedestals. The horizontal anchorage will be effected by field welding triangular-shaped stop plates welded on the under side of the girders. The simple spans will be connected to the continuous

girders by a connecting plate welded on the top flange of the adjacent ends of the girders. Where expansion is provided for, the alternate ends will have this connection plate restrained from lateral movement by welding on the guide bars on one girder on either side of the connecting plate.

Guard Timber Omitted.—Instead of the usual guard timbers, pairs of short angles with their toes pointed together are welded on the top flange. The bridge ties will have a narrow slot to clear the horizontal legs of the angles. In this manner the ties will be held from a movement in either direction. Inner guard rails will be installed.

Bent Design.—Much study and investigation was given relative to the design of the bent, both as to material and pile spacing. Study developed that unless submarine bracing was used a bent of plumb piles was uneconomical for an unsupported height of 30 feet. Models were made and an extensive research conducted. It developed that a four-pile bent with all piles battered and the inner section of the projecting center line of the piles at different elevations provided for the greatest rigidity with the least loading. The effect of the assumed lateral forces in accordance with the design has a longitudinal bracing. The top of the rail is only 12 feet above mean low water and any bracing would have necessarily been shallow, and was found to be unnecessary.

The cap consists of two 18″ 58 lb. channels with the backs welded to the flanges of the piles and a cover plate on the top. About three feet above the water line a transom beam of two 10″ channels is welded on the bent similar to the cap. The transom beam serves two purposes: (a) it protects the piles from damage by collision by making the four piles act together, (b) the resisting movement developed in this transom beam reduces the bending at the cap from lateral forces.

Wrought Iron Protection Plates.—The water in the river being more or less salt, it was decided to protect the piles at the water line. The pile section is to be sealed up in genuine wrought iron plates. Wrought iron plates were flanged in a "U" shape to fit between the flanges and the web of the pile section. These plates extended beyond the flange. Flat wrought iron plates were then placed on the outside of the flanges, thus covering the surface of the piles. Narrow bars were then inserted near the edges of the flange. These plates, all 6′-0″ long, are placed on the pile section using it as a template. Thin shims are slipped between to provide clearance. The sleeve, thus formed, is tack welded then slipped off the pile template and finish welded. After the piles are driven to bearing, the protection plates are slipped down on the piles immediately below the transom beam to set approximately three feet above and below the water line. The sleeves are field welded around the top to the pile making a water seal.

Pedestals.—The body of the pedestals, (See Fig. 7), is made from the 14″ pile cut-offs, cutting off a length of pile 7″ on one flange and 19″ on the other flange. The top of the pedestal, or the 7″ section, is then extended out five inches on either side with plates making the top of the pedestal 7″ x 24″. Stiffener plates are set in between the

flanges being 4″ centers at the top and about 13″ centers at the bottom. A pad 4″ x 12″ is welded on the top of the pedestal which provides the bearing for the girders. Blocks about two inches high are welded on the top. These blocks will clear the 12″ flange of the girders about ⅝″. Thin lateral shims, which nest, will be inserted between the flange and the blocks. The shims can be put on either or both sides as required for any lateral adjustment necessary. The pedestals are field welded directly to the bent cap. One and one-half inch bolts come up through the blocks and hold a large washer which will clamp down on the girder flanges at the stiffeners. The uplift on the girders will be taken by the bolts. Approximately one-half of the pedestals are made with an eccentricity of one inch, in a longitudinal direction, as positioned in the structure. The pedestals when set on the cap may be shifted longitudinally one inch. Provision is thus made to care for the inaccuracy in positioning the bents. Should it become necessary to place vertical shims to provide for inaccuracy or settlement, a vertical shim may be placed on the pedestal pad and the adjustment made in the pedestal bolt.

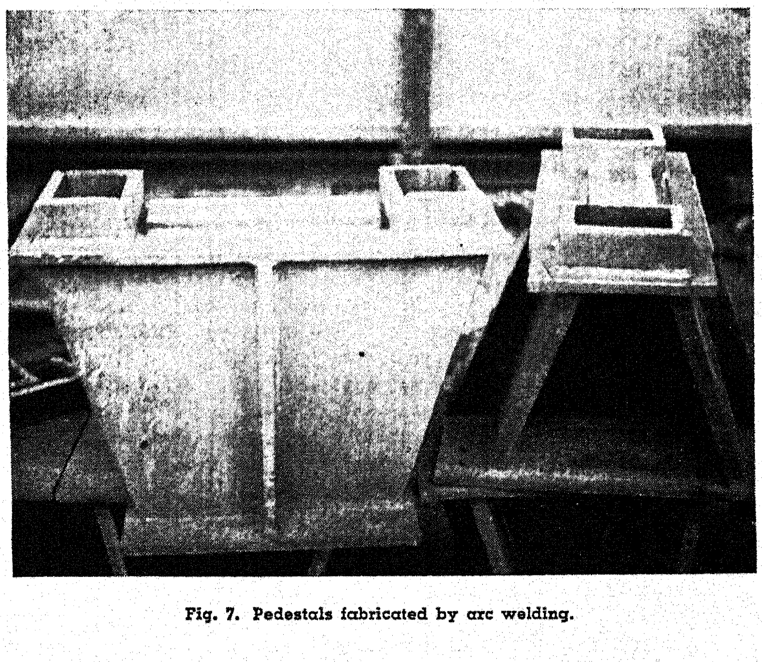


Fig. 7. Pedestals fabricated by arc welding.

Lagging of Piles.—14″ x 12½″ by 89 lb. bearing piles are used. Timber lagging was adopted. Heavy shoes cut off from the chord of the old girders removed from the old structure were welded two feet from the tip end of the piles. A cap or head was welded 18′3″ above the shoe. Two 6″ x 12″ wedges, and two 6″ x 12″ lagging sections all 18′ long, were used in making a displacement pile, providing a tip section approximately 14″ x 14″ and a butt section 14″ x 28″. The tapered

timber lagging extended beyond the flanges except at the tip. The flanges of the pile were extended to the face of the timber lagging at mid point of the timber and at the cap. Steel straps were placed at the shoe, at midpoint and at the cap securing timber lagging.

Single Track Structure.—The new all steel trestle approaches are being built single track and on the common center line between the two main tracks. The double track bascule span has four lines of stringers, all being spaced 6′6″ centers. The track centers of the double track are 13′0″. The present operation is over the southbound track on the bascule. When the new bridge is put in service, the deck on the bascule will be shifted to be carried on the two inside stringers. The girders of the new spans are 6′6″ centers. If and when it becomes economically justified to build a double track bridge it can be done by widening the bents. Additional piles can be then driven on either side and the cap extended. Two more lines of girders can then be installed and cross frames act as struts to tie to the single track girders. It will only be necessary to shift the deck. If the structure had been built on the center line of either of the tracks, a duplicate trestle would have been required for double track service. Due to the limited lateral room available in the vicinity of the draw span, the existing track over the bascule has been shifted approximately 12″ to provide room for driving bents adjacent to the draw. These bents which are carrying shorter spans are three pile bents with plumb piles.

Advantages of Continuous Spans.—Due to the elastic deformation of the 36″ girder beam, there can be considerable settlement in an individual bent without seriously over-stressing the girders.

The interior bents of the continuous girders carry approximately one-third more load than the end bent. Each bent is designed for concentrated lateral forces in addition to the usual load. In the case of simple spans the lateral movement of any one bent would cause rotation of the two simple spans involved about the adjacent bents. In the three span continuous girder, any lateral movement in a bent is carried through the horizontal truss of the lateral bracing to adjacent bents. Each bent is designed to carry the assumed concentrated lateral load. This design, therefore, not only provides a higher factor of safety, but provides a structure much more rigid in service. The piles are driven with a safety factor of six. It is therefore highly probable that there will be no progressive settlement of the piles.

Invitations for Bids.—Shop detail drawings were prepared for the superstructure, based on complete arc welded details. These, together with specifications, were sent out to steel fabricators inviting proposals for furnishing the fabricated steel. When received, the quotations were considered entirely too high. One fabricator submitted an alternate for riveted construction with a slight reduction in the proposal but a great many of the necessary details were altered making the proposal entirely unsatisfactory, regardless of price. Even the quotation received on the alternate riveted construction was considered too high. Quotations were then received on the furnishing of the steel plates and shapes from

the mill and estimates prepared, predicated on the fabrication at the site of the work. This estimate included the erection of a temporary plant and purchase or rental of all necessary equipment.

Saving in Fabrication at the Site.—It developed that a saving of approximately 15% should be effected by doing our own fabrication after writing off the loss in dismantling the plant. Another attractive feature was that the work would all be done at one location. The railway has in the past done considerable arc welding on bridge structures, both in new structures and in reinforcing existing bridges.

The writer has in the past personally shop inspected practically all the welded fabrication which has, heretofore, been contracted. The convenience of having the entire work at one place is evident. Another attractive feature was, that we would use pile cut-off for incorporating in certain details. Further, by having the work done under our supervision, we would have better control of the progress and quality of the work.

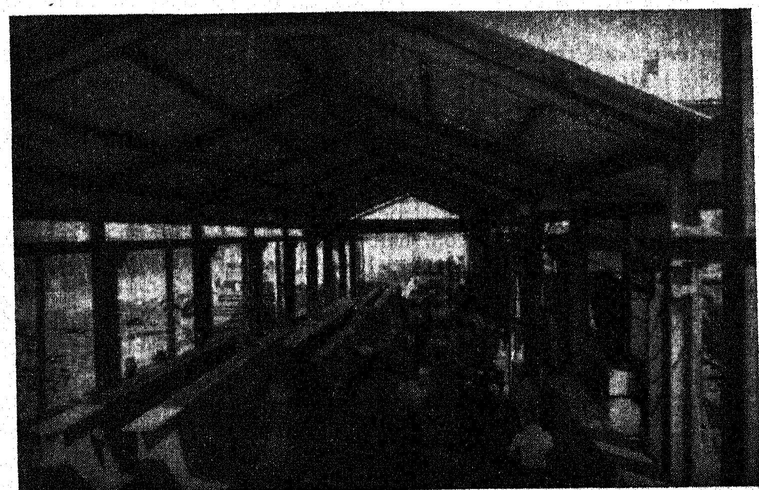


Fig. 8. Fabricating shed, erected at the site by arc welding.

Fabrication by Our Forces.—Structural steel plates and shapes, approximately 750 tons, were ordered from the mill. About 10 tons of light beams and stanchions were ordered for the erection of the fabricating shed. Due to the present unrest in labor conditions, it was decided to have the entire lot of steel delivered at one time. We had three short stub tracks available, two of which had been connected to old dock trestles. The decks of the trestles had been carried away by a storm but the piles remained. A 29′ deck girder span which had been removed by the contractor when the test piles were driven, was available. The laterals were removed, the girders were spliced together into a 58′ overhead gantry over three tracks, and was erected by the

contractor on these temporary supports. All the balance of the erection of the plant was done with our own forces. A light tower of angles was built and placed on a push car for erection.

Welded Fabricated Shed.—6″ stanchions were used in making the welded frames for the shed which is shown in Fig. 8. These frames were a continuous beam. Triangular sections were cut out, the one flange being bent and the section welded. Four inch "I" beams continuous were used for purlins. This shed was practically a duplicate of a covered shed we had recently fabricated and erected at Miami. This construction is as economical as timber construction. The shed can later be removed and used for a covered freight shed. The rigid frame centers were 16′6″. Stub columns were inserted supporting a crane runway of 90 lbs. 33′ rails, the rails serving as a beam as well as the crane rail. Intermediate supports were put under the rail cutting the span to 8′3″. The shed is 132 feet long and 20 feet wide set over the track. The shed is 50′ from the large gantry. The crane runway extended clear through the shed and under the gantry, being 200 feet long.

The two dock trestles were rebuilt with scrap material. A storage rack was built to receive the lagging timber which was delivered by truck from the mill. A crossing was made, to connect our tracks with one track which is used for loading automobiles. Two more overhead gantries were built, both over one track.

The following new equipment was purchased: 2 five-ton crane ends, 2 five-ton hoists, 1 two-ton hoist, 1 one and one-half ton hoist, 1 two-ton trolley, 1 one-ton trolley, 3 one-half ton trolleys, 1 portable electric hammer, 1 portable electric grinder, 1 portable automatic flame cutter, welding cable, electrodes, cutting tips, etc.

The following equipment was rented: 6 electric driven arc welding machines, 2 gasoline driven arc welding machines, 2 portable acetylene generators.

The net cost of constructing and later removing the temporary shed, four gantries and crane runway, track changes and trestle extensions, extending power lines and installation of equipment was $5,500.00. The cost, together with the current expenses such as water and lights, amounts to an overhead of approximately 15% on the fabrication performed.

Material Unloaded.—Seven Hundred Fifty tons of structural steel material was received, classified, and stored. The lagging on most of the piles was applied outside the shed. The cutting was largely done by the automatic cutting machine and with use of a portable carbic generator. Approximately 50 tons of the webs, removed from the old girders, were cut up and used in lagging the piles. The cross frames were fabricated first and stored on a flat car. Assembly of the girders and pedestals was started. The girder beams were brought in. The stiffeners and lateral connections were applied. The simple spans with the shallow ends had the web cut out. The flanges were bent by heating with a hand blow pipe. When the metal was at the correct heat the flanges were bent up by raising with one of the trolley hoists. They were allowed to cool and then welded. The cover plates were applied to these girders.

The cover plates were tapered down to a point so as to reduce the stress due to an abrupt change in section. A small overhead trolley was built to extend over the flat car and into the shed. When the cross frames were required they were picked up by the small hoist and handled into the shop.

Shop Assembly of Spans.—The girders were shop assembled in the following manner. The cross beams were laid on the rails of the track in the shed and levelled. The girder beams were then set on these cross beams. The cross frames were then set in. The girders were clamped together using vertical angles on the outside of the girders, with rods running across, threaded and with nuts. Any lateral bow in the girder beams was then removed by blocking and pulling with a hoist. The laterals were then applied. They were placed on the under side of the lateral connectors. They were pulled up tight in position with the crane and tacked. The tie spacing was made standard, throwing the odd spacing at the ends. A template for setting angle tie spacers was used. The tie spacers were set in the slots in the template and tacked. The welding was then completed.

It was necessary of course to have the bearings of the girders in the same plane. When the girders were finished the bearings were checked with a straight edge and ground where necessary. Fabricated spans were stored outside the shed where they were convenient to the erector.

Cross Welding in Tension Avoided.—Cross welding on members to carry tension was avoided. The stiffeners in contact with the chord members to take tension instead of welding directly to the flange were welded to a diamond shape filler plate. This filler plate was then welded to the inside of the flange, the lines of weld of the filler being at an angle of 45 degrees with the girder. The top diaphragm and the lateral Tee connectors were bevelled off, so the bearing to the flange would be on the inside portion of the flange.

Beams Cambered.—The longer spans had the beams cambered at the mill. It was recognized that the welding of the spacers on the top flange of the spans would have a tendency to shrink the top flange to some extent. Care was exercised in welding on the tie spacers to avoid excessive heating. The loss in camber in the 80′ spans was approximately one-half inch due to this welding.

Shop Fabrication Near Completion.—The only work which was not performed in the shop was the machining of the pedestals. The pedestals, which weigh 200 lbs. each, were faced off on top and bottom.

The shop fabrication at time of this writing is 70% complete. The shop welding totals approximately 34,500 lin. feet. The work has progressed ahead of schedule. The field erection is now in progress. The field welding totals 7,500 lin. feet.

The net cost of unloading, cutting, fitting and fabricating the girders and pedestals amounting to 300 tons, based on the completed work is $30.00 per ton, which is a saving of $12.00 per ton under the lowest bid received.

The cost of the welding is as follows:

COSTS OF SHOP WELDING

Part	Electrode	Labor	Power	Machine Rental	Total	Unit Cost Per Ft.
W. I. SLEEVES						
¼" 8400 lin. ft.	$163.20	$537.60	$126.00	$184.00	$1010.80	$ .144
PEDESTALS AND GIRDERS						
¼" 5000 lin. ft.	97.20	322.00	97.00	100.00	616.20	.148
⅜" 4200 lin. ft.	176.40	502.40	126.00	184.00	988.80	.282
⅜" 6000 lin. ft.	260.00	708.00	186.00	250.00	1404.00	.281
PILES						
½" 3600 lin. ft.	314.00	820.00	216.00	300.00	1650.00	.55
TOTAL 27,200 lin. ft.					$5669.80	

Twenty per cent overhead added to arrive at total cost.
Average cost of welding per ft. $ .25.

Field Erection.—Field welding is being done by railway forces using two portable gas driven welders. The driving is being done from temporary bents. When a bent is driven, clamps are bolted on, the channels of the caps set on an erection seat, on the outside piles of each bent, clamped and welded. An average of four piles per day have been driven. There is approximately 9000 lineal feet of field welding.

General.—The construction of this bridge, together with the fabrication at the site, is pioneering. It is believed however that within a few years this type of work will be commonplace. With the proper organization any railway or company can do this same class of work with a saving both in first cost and in maintenance. One of the greatest benefits in welding is the ability to put the metal where it is needed. Connections are reduced in size and eccentric connections, and connections with secondary stresses, can be avoided.

Maintenance.—A structure such as this is free from open joints which invite corrosion. A check-up on a former welded structure we built indicated that the welded structure could be painted at less labor cost than to paint the rivet heads alone in the riveted structure which it replaced.

Saving in Cost.—The cost of this structure is about one third less than any other type of permanent construction yet developed.

The saving of this type of construction at locations where it would be adaptable is very great. The railways in this country alone spend millions of dollars every year in new bridge construction.

Conclusion.—The economical use of arc welding in bridge construction is in its infancy in this country. However, there have been so many demonstrations of its value to safely withstand impact stresses and fatigue, that it will undoubtedly soon be in general use.

Chapter XIII—Design of An Arc Welded Elliptical Tainter Gate

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The improvement of rivers for the betterment of navigation has required in many cases the use of dams with movable gates for the control of the varying discharges and the passage of flood waters. A widely used structure of this type consists principally of large movable steel gates supported by concrete piers. Such gates must be of rugged construction, capable of supporting the enormous water loads between piers, and of withstanding the buffeting and abrasive action of ice, drift, snags, and silt-laden water. Other desirable characteristics are long spans so as to provide wide openings between piers for the passage of ice and drift, and for the minimum obstruction of stream-flow during floods. Gates of both the tainter and roller type, and combinations thereof, have frequently been utilized.

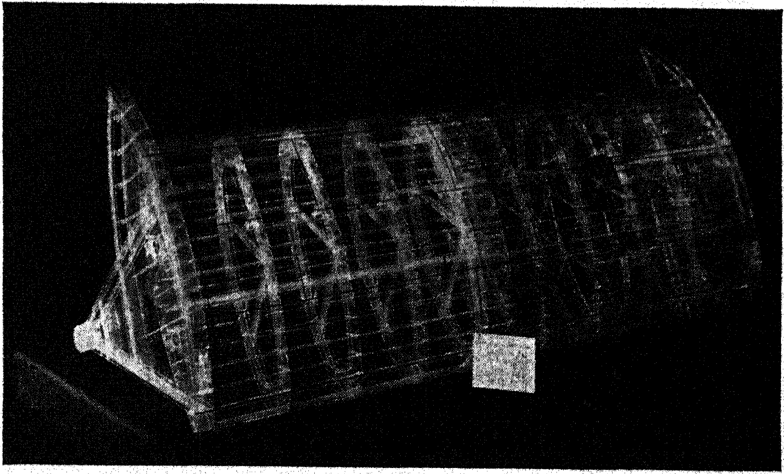


Fig. 1. Model of elliptical tainter gate—1/24 actual size.

Types of Gates.—Roller gates have long possessed certain inherent merits such as ruggedness and susceptibility of being utilized in large sizes. Such gates with spans of 60 to 100 feet, and effective damming heights of from 20 to 25 feet are not uncommon. However, roller gates are rather costly in comparison with tainter gates. Until recent years, the latter were deemed too small in size for their exclusive use in well balanced navigation structures. Spans of 40 feet with effective damming heights of 20 feet represented a practicable limitation in size.

Likewise, until recent years, neither tainter gates nor roller gates were designed so that they could be submerged or lowered below the normal pool level to permit the passage of ice or drift over, rather than under, the gates. This feature of submergence has been incorporated into the design of numerous late structures.

Tainter Gates.—Early tainter gates consisted, in general, of horizontally framed beams or trusses to which a skin plate was attached on the upstream side, either directly or through a series of vertically framed ribs. This skin plate formed the watertight membrane. Since these gates were not to be overtopped by the water, no plating was necessary to protect the beams. A section through the gate resembled the arc of a circle.

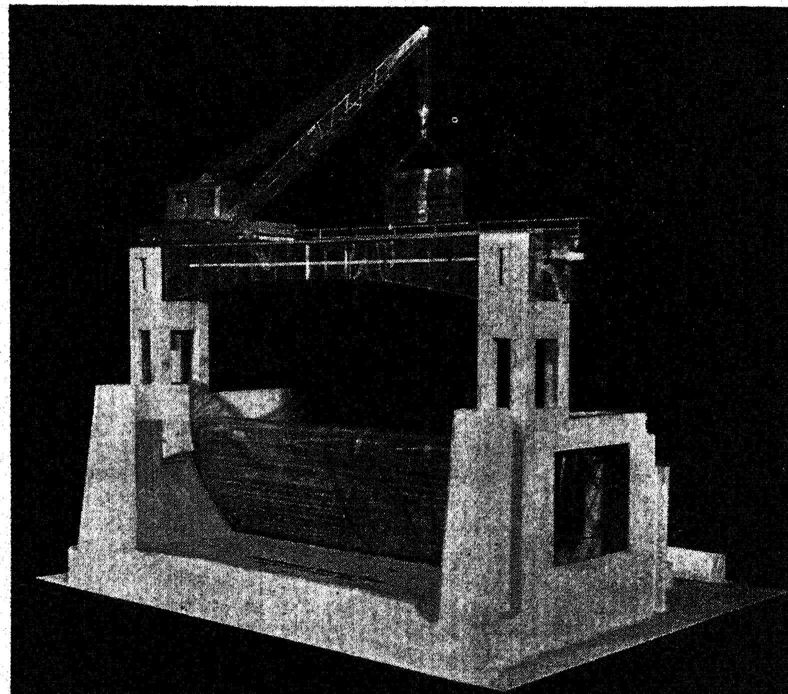


Fig. 2. Model of elliptical tainter gate with gate in lowermost position.

In the development of longer spans, the principal load-carrying members became heavy plate girders and the incorporation of the submergible features necessitated the carrying of the skin plate over the top of the gate and part way down the downstream side in order to house and protect the girders. Deeper depths of submergence resulted in the extension of the skin plate to cover the entire downstream side. The cross-section of such a gate resembled an ellipse. Gates with 60-foot spans and damming heights of 25 feet which incorporated

these principles have been designed and constructed. With complete enclosure of the girders, it was possible to utilize a large portion of the skin plating as effective flange area for the girders with a resultant economy in gate steel. Further development led to entire elimination of the heavy girders. This evolution resulted in the moment-resisting shell elliptical tainter gate as illustrated in Figs. 1, 2 and 3.

General Features of Design.—Engineering has been said to be the accomplishment of the most economical design consistent with the essential criteria of adequacy and safety. In the case of this structure, the possibilities of reduction in cost were subjected to careful study. It was determined that three primary features of design might be utilized to effect material economy and at the same time enhance the satisfaction of the aforementioned criteria. These features are use of the moment resisting shell, low-alloy high-tensile steel and arc welding.

Moment Resisting Shell.—The moment-resisting shell elliptical tainter gate employs for its principal load carrying member a beam approximately elliptical in cross section. This beam, or shell, consists of a tubular skin plate reinforced by longitudinal ribs. Since the shell is capable of supporting the loads, heavy girders or trusses within the gate are eliminated and the interior bracing is reduced to comparatively light transverse frames. The frames support the shell of skin plating and ribs against collapse due to local bending and shearing stresses. End reactions from the shell are transmitted into the trunnions and thence into the piers by means of trunnion arms which consist of the end shield plates, the heavy struts, and the trunnion bearing supports. Gates of this type provide a rugged and efficient structure for the passage of water beneath, or water, ice and drift over the top.

The elliptical shell, which serves the principal purposes of forming the water-tight damming membrane and of resisting the enormous thrust of the water, is capable of long-span construction. Eighty feet between piers was selected for this structure. This represented an increase of 33⅓ per cent in the span of any previously known constructed tainter gate. The selected length, however, was not controlled by any limitation inherent to the shell, but was governed largely by the trunnions and anchorages. An 80-foot span at this dam can produce reactions of over two million pounds per gate. The comparatively expensive roller gates were entirely eliminated in favor of these more economical elliptical tainter gates. This was accomplished without sacrifice of the desirable qualities which formerly were peculiar to roller gates.

Alloy-Steels.—The use of higher working stresses and their attendant economies through the years of structural steel construction has been predicated almost entirely upon progress of the steel industry in the production of economical products of consistent quality which are better suited for fabrication into heavy structures. The recent advent of certain types of low-alloy high-tensile structural steel appeared to offer many desirable qualities for use in gates for the control of rivers, viz.: an increase of approximately 75% in elastic limit as compared to ordinary medium carbon steel; from two to five times the

resistance to corrosion; excellent qualities for arc welding; and, but slight increase in cost over carbon steel. It was decided to design these gates for fabrication of this low-alloy high-tensile steel so as to take advantage of a very material weight reduction and a superior resistance to the ravages of time by corrosion.

It appeared that the advantage of economy and durability of a moment-resisting shell of alloy steel might further be enhanced by the elimination of rivets in favor of arc welded connections. However, it was felt that such a step properly called for careful study and investigation.

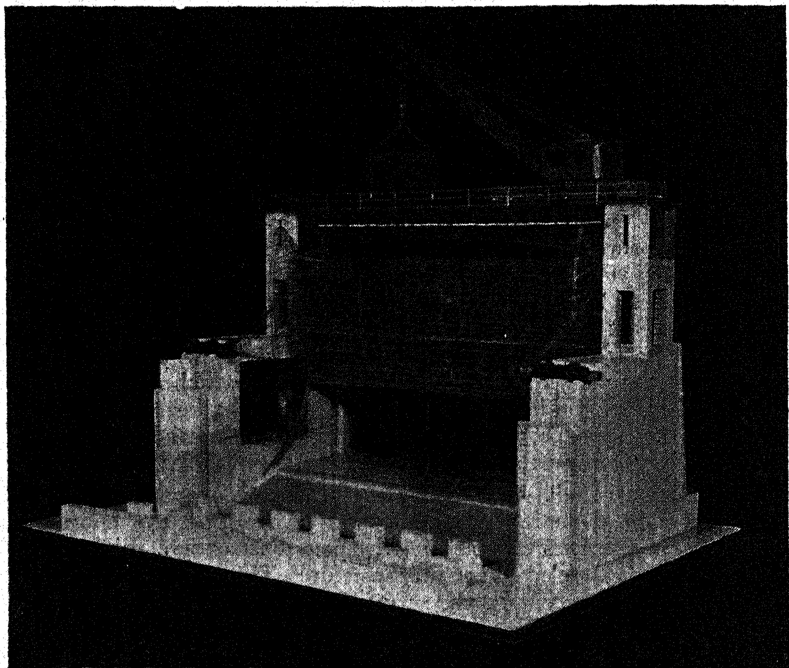


Fig. 3. Model of elliptical tainter gate with gate in uppermost position.

Development of an Arc Welded Design.—The merits and limitations of arc welding were subjected to careful study and investigation before a decision to permit its general use in this structure was adopted. Conservatism and inertia existed on one hand, as opposed to a desire for economy and progress on the other. It is deemed natural that such conservatism should manifest itself in the minds of engineers charged with the responsibility of adequate design. The consequences of a failure with its property damage and frequent loss of life, eliminates any justification for the use of experimental processes. Most designers of today have been trained, since the start of their engineering careers, in the belief that fabrication of structural steel is best accomplished by means of rivets. The riveted connection has long ago run the gaunt-

let of experimentation. It is to be expected that a relatively new process, such as arc welding, should be viewed with some amount of skepticism.

Investigation.—Serious consideration of a general use of welding by this organization gained momentum about two years ago. The investigation which resulted involved consultation with recognized authorities of both the welding and riveting industries, a study of pertinent articles and papers, analysis of the results of competently performed tests, and tests and demonstrations performed for this organization. Numerous demonstrations of various types of welds in all positions under both favorable and unfavorable conditions were witnessed. Destructive tests proved welded connections equal or superior to parent metal parts joined. It became apparent that modern shielded arc welding equipment largely eliminated the human element. The resistance of welded connections to shock and fatigue was thoroughly considered. Modern X-ray equipment, and radiographs of various types of welds from poor to excellent, were examined. The methods and needs for stress relieving were studied. Likewise studied was the subject of properly planned welding procedure to eliminate or minimize "locked up" stresses and distortion. The welding industry was called upon repeatedly for both information and advice. The generous co-operation received was invaluable.

Decision to Use Arc Welding.—As a result largely of the foregoing investigation, this organization accepted welding as a developed and proven art. It was convinced that welding with the shielded arc, with the use of proven equipment, qualified operators, and competent inspection, could be relied upon to produce connections as reliable as the parent metals joined. It recognized that the modern arc welding processes offer decided potential advantages of economy, durability, and simplification of design.

However, the potential economies of arc welding were not accepted carte-blanche. Although the feasibility and safety of welding were considered well established, it was not entirely apparent that sufficient structural steel shops would bid on a welded design of this type to result in the competition necessary to achieve representative prices. Since a riveted structure would satisfy the minimum needs of the government and would be entirely satisfactory, welded design was required to compete with riveted design on a direct dollar and cents basis. Bids were invited for each method of fabrication. To insure true comparison, separate welded and riveted designs and drawings were prepared. Thus, the welded proposals did not merely constitute a substitution of welded fabrication on designs intended primarily for riveting.

Standards of Design.—Since the elliptical gates constitute the leading example of welded design in this dam, the principles incorporated therein will be described in lieu of an enumeration of all welding features used.

The design of the welded gate was accomplished with the intent of utilizing the most efficient and structurally sound types of welded connections. Serious effort was made to present a design well in accord

with the canons of sound and economical welding practice. Recognition was made of the fact that welded connections may be made as strong and as reliable as the members joined without the use of reinforcing plates. The economical types of welded connections which stress the weld metal in tension and compression were considered preferable to the more costly shear connections. Lap joints and splice plates were eliminated in favor of full section beveled, or "Vee'd" butt joints. Connection, or "fayed" flanges were replaced by tee joints. Since rivet and bolt holes have no major place in welded construction, calculations of stress were generally based upon gross, rather than net, sections. Splices were permitted at locations, or points largely to suit the convenience of the fabricator. The advantages of flame cutting have been recognized and the free use thereof, subject to the control of the specifications was permitted.

The photographs of the pyralin model, as shown in Figs. 1, 2, and 3 illustrate a small scale replica which was constructed for the purpose of better visualizing the finished appearance of a gate. This model illustrates the type of framing for welded construction in one of its halves and the riveted alternate in the other. The drawing, Fig. 4, sets forth the general appearance and the relationship to the masonry structures of the welded gate. Details of the welded design are shown in Figs. 5, 6, and 7. Pertinent extracts from the specifications follow.

Extracts from Specifications

General.—The movable-gate section of the dam shall be provided with 15 structural steel tainter or sector type gates fabricated and installed as shown. The gates shall be equipped to operate by individual hoists mounted on the service bridge girders.

Type.—All gates shall be 25 feet in height from the concrete sill to the crest when in the normal position and shall operate between masonry piers with 80 feet clear openings. They shall be of the submergible type, capable of being lowered 8 feet below the normal pool elevation. When in lowermost position, the gates shall bear on the steel gate stops.

(a) At each end of the gate there shall be an end projection. The rubber seals shall be attached to the end projection and be constructed and fitted to form continuous contact with the seal plates throughout their entire length.

(b) Side seal plates shall consist of corrosion resisting steel plates reinforced with structural steel stiffeners and embedded in the faces of the concrete piers.

(c) Heater Recesses.—Structural steel channels shall be welded to the back side of each side seal plate to form watertight conduits for installation of electric heating elements.

Trunnions and Tension Anchorage.—Prior to machining the trunnion castings, the trunnion arm connection plates shall be welded thereto. Care shall be taken to minimize distortion. After welding and prior to machining, the trunnion shall be stress-relief annealed in an approved manner.

Metals

Structural Phosphorus-Chromium Steel.—Phosphorus-chromium steel shall conform to Federal Specification QQ-S-751 for "Steel, Structural (Including Steel for Cold Flanging) and Steel, Rivet; (for) Ships other than Naval Vessels," except for modifications in the chemical and physical properties as follows:

Chemical Properties:	Per Cent
Carbon	.10 maximum
Manganese	.10 to .50
Phosphorus	.10 to .20
Sulphur	.05 maximum
Silicon	.50 to 1.00
Copper	.30 to .50
Chromium	.85 to 1.50

Physical Properties:

Tensile Strength, lbs. per sq. in....70,000 minimum
Yield Point, lbs. per sq. in............50,000 minimum
For heavy sections or when annealing is required each of the above tensile properties may be reduced up to 5,000 lbs. per sq. in.

Spot or Surface Conditioning will be permitted, where it does not affect the strength or usefulness of the piece. For plate, sheet, strip and bar shapes the maximum-depth of grinding shall not exceed 7 per cent of the thickness. For wide flange shapes and structural shapes weighing more than 50 pounds per foot, such conditioning shall conform to Federal Specification QQ-S-711 for "Steel; Structural, (for) Bridges," "Amendment 1."

Fabrication:

General.—(a) Before laying out or working in any way, material shall be thoroughly straightened by methods that will not result in injury, except that sharp kinks or bends will be cause for rejection. Finished members shall be free from kinks, bends or winds. Shearing shall be neatly and accurately done, and all portions of the work neatly finished. Reentrant cuts shall be made in the best possible manner; where they cannot be made by shearing, a rectangular punch may be

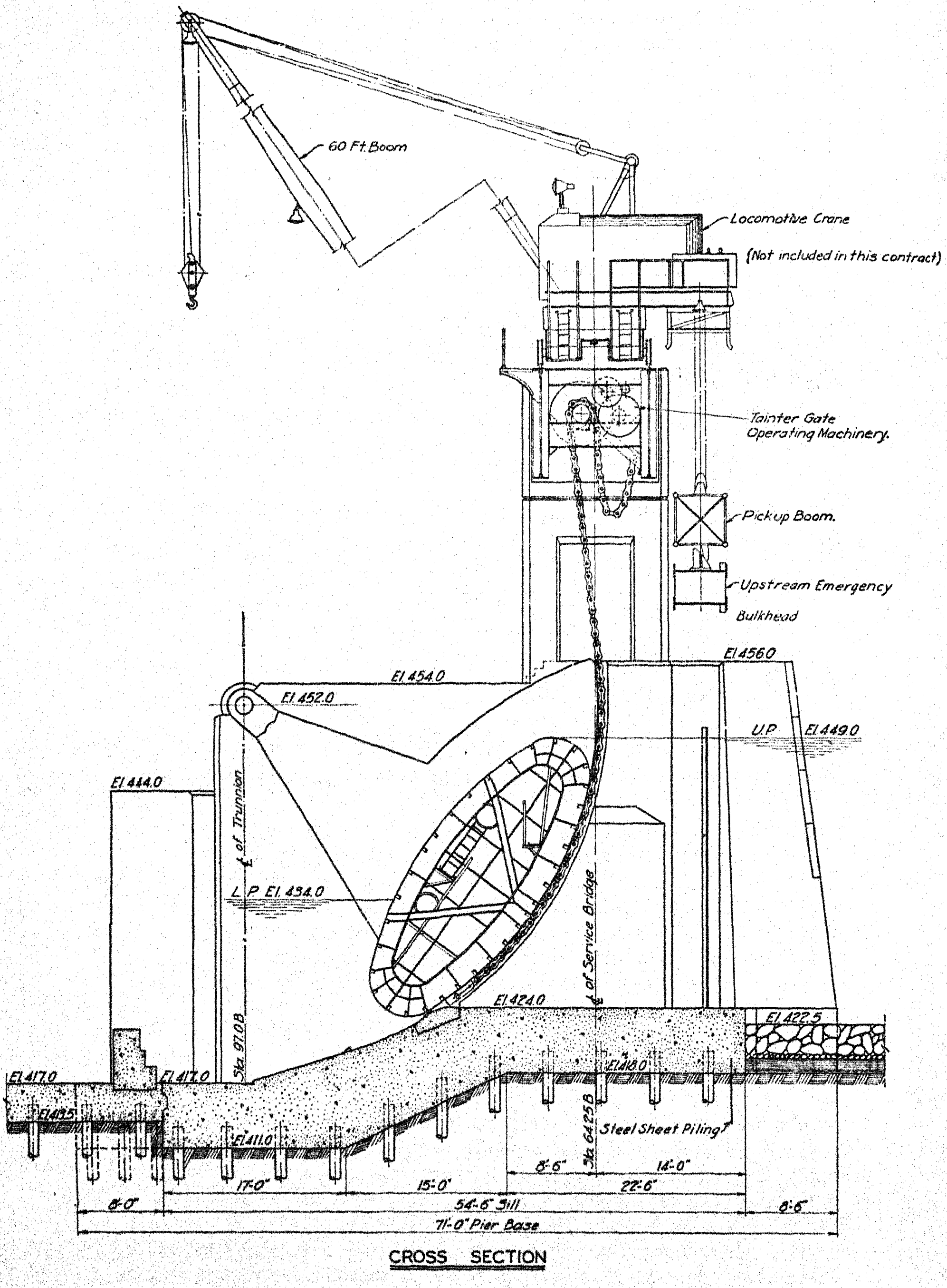


Fig. 4. Tainter gate—general arrangement. See also page 633b.

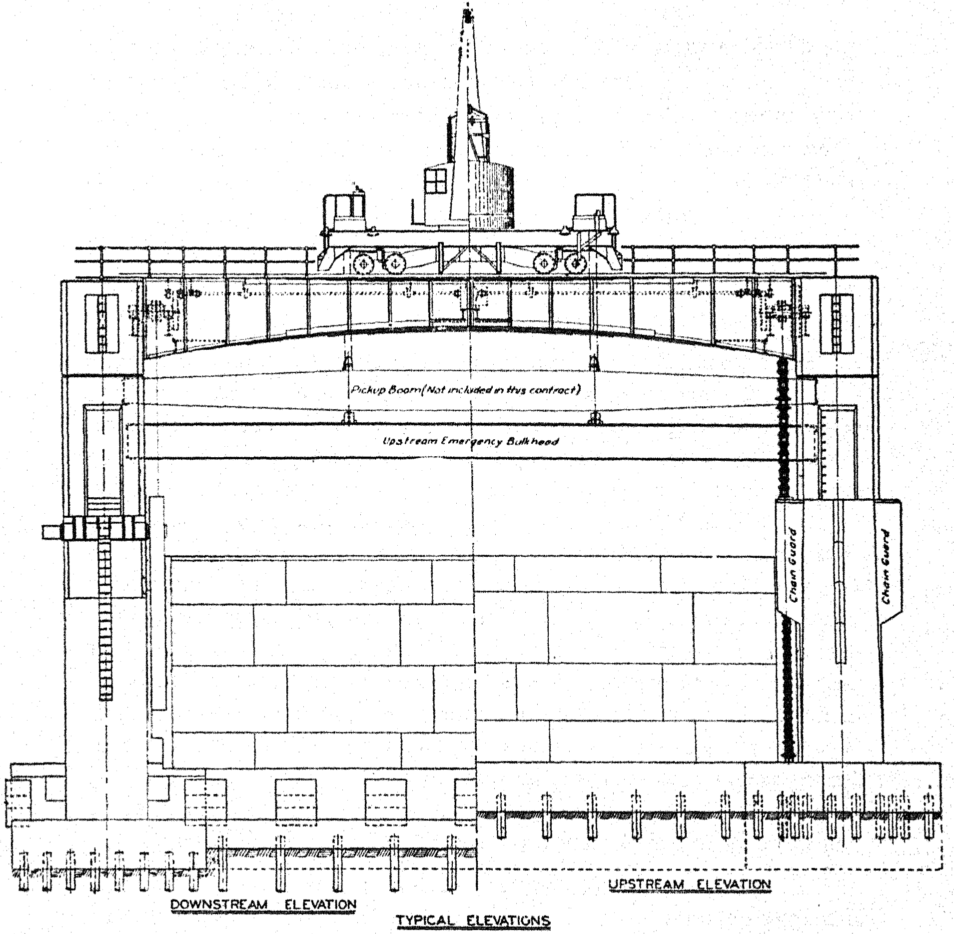


Fig. 4. Tainter gate—general arrangement. **See also page 633a.**

used. Corners shall be square and true. Flame-cutting machines may be used for cutting instead of shears or saws. Where approved by the contracting officer, flame cutting by hand torch may also be used. All places where flame cutting is proposed shall be definitely shown on all shop drawings submitted for the approval of the contracting officer. All bends, except for minor details, shall be made to cast iron dies. Where heating is required, precautions shall be taken to avoid overheating the metal and it shall be allowed to cool slowly. All bolts, nuts, and screws shall be tight. The top of all steel floor grating shall be installed flush with abutting curb surfaces. The ends of all steel and wrought iron pipe, except for handrailing, shall be reamed.

(b) Dimensional Tolerances for Structural Work. The major dimensions of any structural steel structure shall be within ¼ inch of those shown on the drawings, unless otherwise specifically authorized. The dimensions shall be measured by means of an approved calibrated steel tape of the same temperature as the structure at the time of measurement. Dimensions of plates shown on drawings of the gates are suggestive only, and the contractor, at his option, may use plates of any size obtainable, except that on the end shield of the welded gate, the splices between ⅜, 7/16, and ½ inch plates shall be as shown.

Welding and Flame Cutting.—(a) General. (1) Unless otherwise authorized, all welding shall be by the shielded electric arc welding process, and shall conform to the provisions of the current specifications of the American Welding Society applicable to the work to be done, as determined by the contracting officer, and as further specified below. Welding operators shall be qualified, at the expense of the contractor, as required by the specifications of either the American Welding Society, the U. S. Navy Department Bureau of Construction and Repair, or the U. S. Bureau of Navigation and Steamboat Inspection, and the contractor shall certify by name to the contracting officer the welding operators so qualified, and the code under which qualified. In no case shall welding be done when the temperature of the metal is below 10 degrees F, or when inclement weather or physical conditions are such as may, in the opinion of the contracting officer, be unsuitable and impair the efficiency of the welder in making acceptable welds, unless approved steps are taken to correct such conditions.

(b) Filler Metal.—(1) Unless otherwise specified or authorized, all deposited weld metal shall have elastic limits and ultimate tensile strengths not less than those of the respective metals; elongation within 5 per cent of that of the base metal; chemical composition similar to that of the base metal; and, when subjected to approved tests, shall have corrosion resistance at least equivalent to that of the base metal. These properties shall be determined by testing in accordance with the applicable provisions of the current specifications of the American Welding Society.

Welding electrodes and rods shall be of type and grade as approved by the contracting officer and of such chemical composition and physical properties as will produce the characteristics specified above and so adapted to the base metal and thickness of parts to be welded as will insure effective penetration and an intimate uniform fusion of the filler and base metals. The electrodes and coating shall conform in dimen-

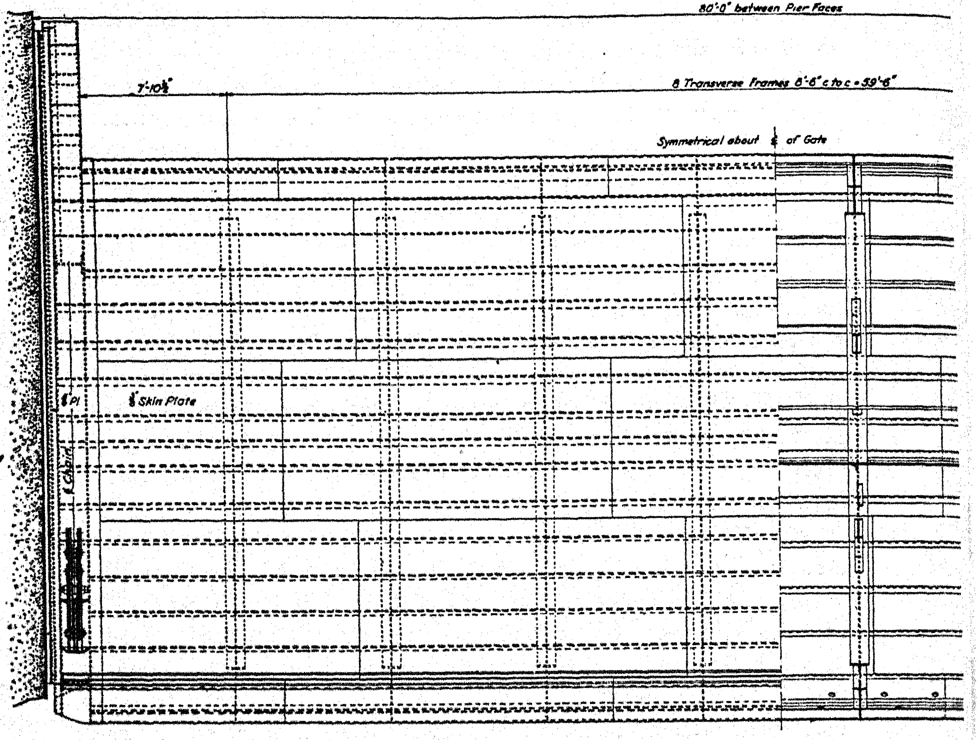
sions and physical characteristics to applicable provisions of the current specifications of the American Welding Society.

Special Workmanship Requirements.—(1) Welding Procedure.

The contractor shall prepare his own schedule of welding procedure for each structure to be welded, and shall submit the procedure to the contracting officer for approval. The procedure shall be in accordance with the best modern standard welding practice, as approved by the contracting officer, and shall be such as to minimize locked-up stresses and distortion of the finished members of the structure. No welding shall be done on any structure until the procedure for that structure has been approved. Should the contracting officer subsequently find that changes in any previously approved welding procedure are desirable, he will so direct or authorize the contractor. Approval of any procedure, however, will not relieve the contractor of the sole responsibility for its adequacy for producing a finished structure meeting all requirements of these specifications.

(2) Welds.—A wandering or skip sequence of welding shall be used on all passes of welded joints. The maximum length of bead, laid in any one continuous or skip pass shall be that which can be laid with one electrode. Unless otherwise specifically authorized, all welds shall be of the type, size and dimensions as shown on the drawings. Welds, 3/8 inch and larger, shall be made in not less than 2 passes; and, unless otherwise specified or authorized, shall in general be made with one pass for each 1/8 inch thickness of base metal, exclusive of back bead. Except in the case of welded sections 1 inch or more in thickness which will subsequently be stress-relief annealed, no electrodes larger than 1/4 inch in nominal diameter will be permitted to be used. In making root welds of fillets or in vertical and overhead welding, unless specifically authorized, no electrodes larger than 5/32 inch in nominal diameter shall be used. In all welding, the application of the first pass shall be given special attention to insure satisfactory penetration and fusion of the filler and base metals. Where the clearance between members to be joined by fillet welds is greater than 1/16 inch, the amount of clearance shall be painted near the joint to be welded and the size of the fillet weld to be deposited shall be the size specified, plus the clearance. When welding double fillet Tee joints, a clearance between members of not less than 1/32 inch shall be provided.

(3) Special High Strength Joints, as indicated on the drawings shall be made with special precautions to insure that such joints are made without flaw. The contractor shall assign to such work the welders best qualified to perform such welding operations.



ELEVATION DOWNSTREAM

NOMENCLATURE OF GATE

GATE:
The movable portion of the structure considered as a whole. Consists principally of a Shell, Transverse Frames, Trunnion Arms and End Projections.

SHELL:
That part of the Gate which forms the Dam between End Shields. Consists of an elliptical tube comprised of a skin plate and the longitudinal ribs.

TRANSVERSE FRAMES:
Structural Cross Frames which support the shell.

TRUNNION ARMS:
Those members at each end of the gate which transmit the gate load into the piers. Each consists of two Struts, an End Shield and a Trunnion Bearing.

END PROJECTIONS:
Those portions of the Gate which form the Dam between the End Shields and the Piers.

◆MATERIAL IN FIXED PORTION OF ONE TAINTER GATE

MATERIAL	ANCHORAGE	HEAD PLS.	TRUNNION SHAFT	SIDE SEAL & TRACK PLATE	SILL BEAM	STOP	WEIGHT
STRUCTURAL STEEL	24,000	4514		3,300	4,101	196	36,111 LB.
FORGED CARBON STEEL			23,400				23,400 LB.
COR. RES. STEEL				1,290			1,290 LB.
PHOS-CHROME STEEL					4,834	766	5,600 LB.
BOLTS-STRUCT. STEEL	382			140	259	50	831 LB.
TOTAL WEIGHT							67,232 LB.

◆ QUANTITIES SHOWN FOR A TYPICAL SPAN WITH WELDED ANCHORAGE AND HEAD PLATES

MATERIAL IN MOVING PORTION OF ONE TAINTER GATE

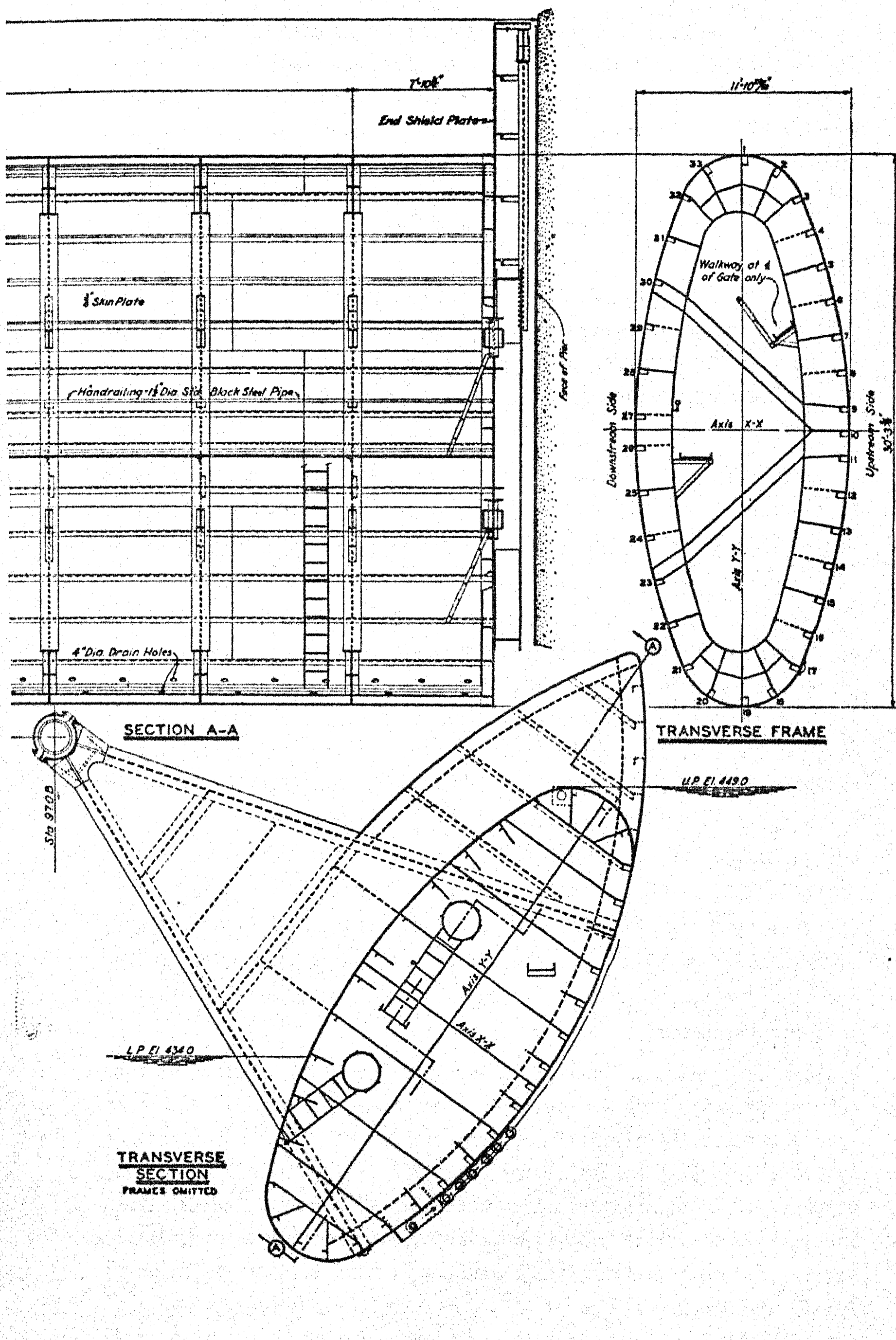
MATERIAL	WEIGHT
PHOSPHORUS CHROMIUM STEEL (INCLUDING WELDS)	197,320 LB.
CAST STEEL (CLASS I)	5,228 LB.
CAST NICKEL STEEL	123 LB.
FORGED NICKEL STEEL	40 LB.
BOLTS-CORROSION RESISTING STEEL	325 LB.
BRONZE-(COMPOSITION 10)	1,401 LB.
CAST BRASS-(COMPOSITION 3)	188 LB.
RUBBER SEALS	967 LB.
PIPE-1½" DIA	230 LB.
STRUCTURAL STEEL (WALKWAYS AND LADDERS)	3,073 LB.
TOTAL WEIGHT	208,895 LB.

WEIGHT DISTRIBUTION

ITEM	WEIGHT	PERCENTAGE OF TOTAL WT.
* 2 END SHIELDS * *	54,230 LB.	26.0
* 8 TRANSVERSE FRAMES	33,732 LB.	16.1
* SKIN PLATES	85,895 LB.	41.1
* RIB ANGLES	29,025 LB.	13.8
* MISCELLANEOUS * * *	6,013 LB.	2.9
TOTAL WEIGHT	208,895 LB.	100.0%

* INCLUDING WELDING.
* * INCLUDING STRUTS, TRUNNIONS & END PROJECTIONS
* * * INCLUDING SEALS, WALKWAYS, LADDERS, ETC.

Fig. 5. Tainter gate—general elevations and sections.



SECTION A-A

TRANSVERSE FRAME

TRANSVERSE SECTION
FRAMES OMITTED

(4) Assembling Devices and Temporary Connections. Preparatory for welding, the assembled elements of members shall be held rigidly in position by the use of approved devices adapted to the purpose, and capable of exerting pressures requisite to remove local distortions and compress the parts into intimate contact except where root openings are required. Bolts may be used for temporary connections provided that the bolt holes are subsequently filled with sound weld metal in an approved manner and ground flush with adjacent base metal, unless otherwise authorized. Welding for temporary connections and bracing will be permitted provided that, where such welded connection does not form a part of a later permanent connection, such weld metal shall be removed approximately flush with adjacent base metal where so directed.

Shop Erection.—Should the contractor propose partial or complete fabrication of welded gates in the shop, he shall submit complete detailed plans for such fabrication procedure to the contracting officer for prior approval.

Field Erection. (a) Prior to the application of any skin plating, the framework shall be assembled by tack welding into place and final complete welding of the framing shall progress ahead of the application of any skin plating. When a plate joint is made, the end of the member opposite the end being joined shall be free to move, except in making closing joints. Where possible, in making these closing joints the joined members shall be temporarily displaced an amount equal to the probable contraction of the joint after cooling so that such members will have a minimum of locked-up stress in the finished work. Closing plates shall be carefully cut to fit with allowance for contraction in the closing joints. Minor discrepancies in the length of the completed gates shall be corrected by machining a proper equal amount from each of the two trunnion thrust rings.

(b) All parts shall be carefully made and fitted together so that after final assembly there will be no interference due to poor alignment or any warping or twisting in the members that would in any way interfere with smooth and satisfactory operation. The bottom seal shall be carefully adjusted in conjunction with the sill beams, to insure close contact over the entire length of the bottom seal, by means of properly aligning the sill beams to contact with the bottom seal prior to grouting the sill beams into place in the sill recesses provided therefor. The rub-

ber side seals shall be carefully assembled to insure close seal over the entire length of the seal plates. Provisions have been made for adjustment in the field of all such parts, but the contractor shall be responsible for the adequacy of provisions made for satisfactory erection.

A basic allowable working stress of 27,000 lbs. per square inch in tension on net sections was selected for the phosphorus-chromium alloy steel. It will be noted that butt joints are rated as 90% efficient, unless reinforced, in which case their efficiencies are rated as 100%. Reinforcement, in this structure, may be defined as the inclusion of a reinforcing bead on both sides of the joint. Reinforcing beads, or back, beads on the roots of welded joints were specified in all cases where such roots would be subjected to bending tension. Butt and tee joints were called for in practically all load-carrying connections. This is exemplified in Figs. 5, 6 and 7 by the butt joints in the skin plates, end shield plates, longitudinal ribs, webs of the transverse frames, and trunnion connections, and by the tee joints between the longitudinal rib angles and skin plate, the skin plate and end shield plate, and the various parts of the end projections. Thirty-two thicknesses of plate, but not to exceed 6 inches on each side of the web, were assumed to act as flange in the case of the longitudinal rib angles, the transverse frames and other similar details. Welds for connections of flanges to webs of beams were proportioned to carry the longitudinal shear at an allowable unit working stress in shear of 14,000 lbs. per square inch across the throats of the fillets.

Erection Procedure.—It was realized that the fabrication and erection of such a welded gate would constitute an evolution which could prove excessive in cost and might result in an unsatisfactory structure. Accordingly, the welding procedure was subjected to careful and thorough study. As a result, the specifications were prepared with a view toward eliminating or minimizing locked-up stresses and their resultant distortions. It was specified that the welding process be shifted at the completion of depositing each electrode so as to utilize a "skip" or "wandering" sequence of connecting each joint; that the size of welding electrodes on parts which would not subsequently be stress relief annealed be limited to ¼-inch; and, that a welding procedure for each unit be prepared for the approval of the contracting officer before fabrication of that unit would be permitted.

Since application of the skin plating appeared to offer a particularly troublesome problem, a suggested procedure for this operation was prepared for the fabricators' use. This procedure was so worked out as to confine welding insofar as practicable to plates which were free

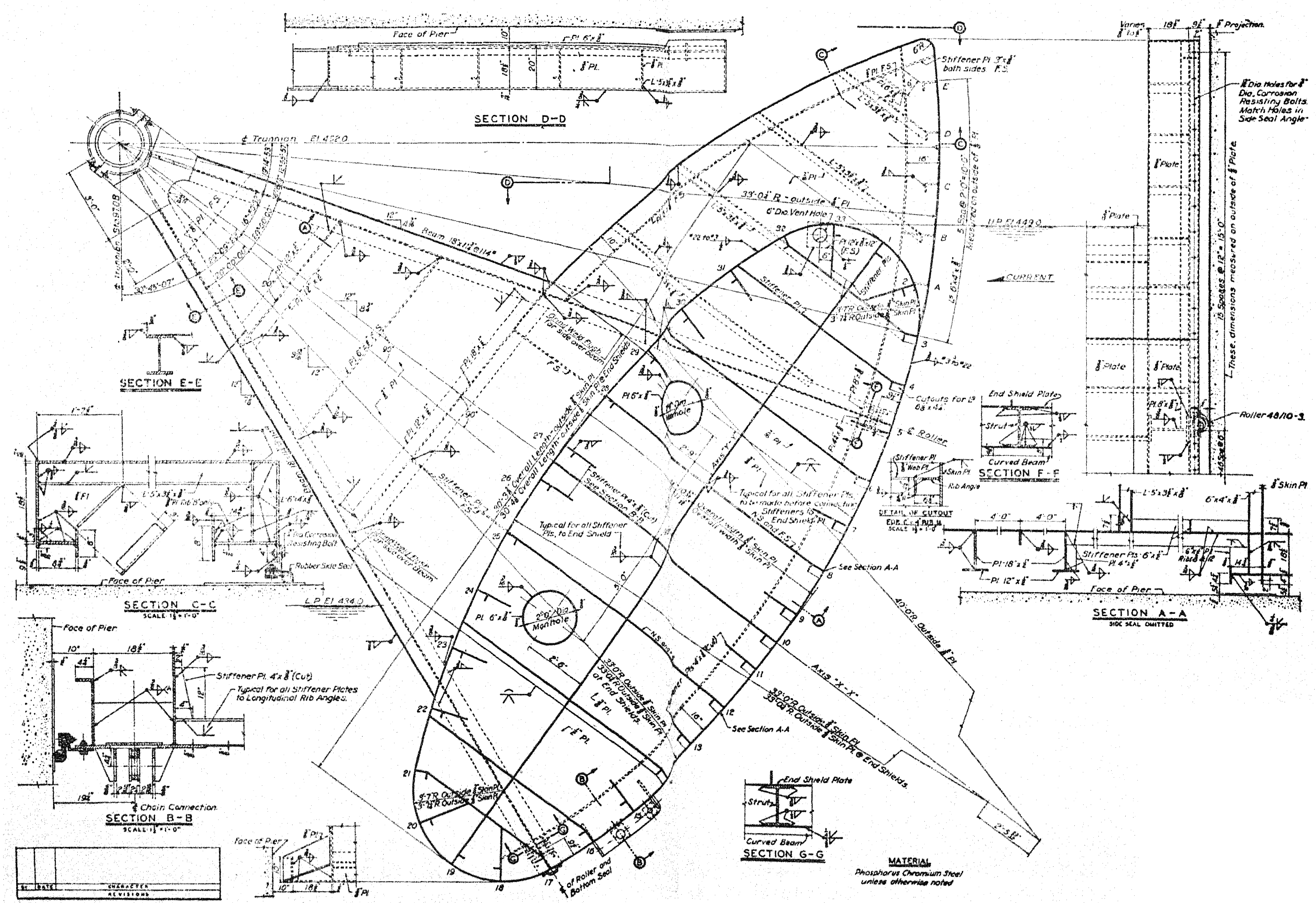


Fig. 6. Tainter gate—section at end shield.

to move. Where this could not be accomplished, liberal allowance was made for distribution of the strain, due to joint contraction, over sufficient plate length to keep locked up stresses to reasonable values. The sequence was developed with an intention to place unavoidable locked-up stresses where they would not be additative to working stresses.

Welded and Riveted Comparisons.—The estimated weight of the welded gate amounts to 209,000 pounds as compared to a weight of 232,000 pounds for the riveted gate. Although the welded gate is 10 per cent lighter in weight, it has a resisting moment in bending 12 per cent greater than the riveted gate. Since metal of less than ⅜-inch thickness was not permitted except in walkways, a full advantage of potential weight economy could not be realized. The simplicity of details together with the marked reduction in number of parts is distinctive to the welded design.

Investigation Observations.—It is realized only too well that it would require a long period of intensive study and investigation for any one person to become even reasonably conversant with all the "answers" in modern arc welding. Therefore, it is with considerable apprehension that the following points, some of which may be original, are offered for what they may be worth. It has been observed on numerous structural drawings that welding information has often been quite sketchy. The single word "weld" with an arrow pointing to the connection frequently constitutes the complete information presented to the fabricator. It is felt that such practice has two possible results, either of which can add considerably to the construction costs. The fabricator can develop a stress analysis from which he can design the connections, or he can put on plenty of weld metal "just to be sure." The fabricator, proficient though he be in his business, should not be expected to understand the forces that must be resisted as thoroughly as the engineer. In the same manner as the designer habitually specifies the structural members, and the number and size of the rivets, so, too, should he designate the type of weld, and the size and length required to satisfy the function of each particular joint.

The subject of proper welding procedure to procure finished products reasonably free from locked up stresses and distortion appears to be one frequently overlooked by designers and fabricators alike. As a result, serious cases of distortion and broken connections exert a strong influence to retard the use of structural welding. It is believed that engineers and fabricators should bear this important phase of construction constantly in mind in the case of every welded structure.

Furthermore, it is felt that the proper provisions should be set up in each set of specifications to require approved welding procedures prior to erection and to make possible close co-operation between the engineer and the fabricator.

The welded designs, as described in this paper, have largely been made possible through a close co-operation with the welding and structural industries. The vast storehouse of knowledge, that was brought to our attention, has been most helpful.

Comparison of Costs.—Bids were invited for both the welded design and the alternate riveted design. This course of action was adopted in an effort to demonstrate to this organization the comparative cost relationship between welded and riveted fabrication for structures of this type. Likewise, it served to prevent unreasonably high bids which it was thought might result if the welding fabricators were not required to bid against riveted competition. Since either the riveted or the welded structures were considered adequate to serve the needs of the government, it is felt that the action taken was well justified. The cost information furnished by this competitive bidding should be of value in determining whether, in similar future construction, welded fabrication should definitely be adopted in lieu of riveting.

Analysis of Bids.—The following table lists the total prices bid for the entire dam:

Summary of Bids

Bidder	Welded Bid	Riveted Bid
1 (Low bidder)	$2,699,142.25	$2,658,171.15
2	3,014,991.70	3,079,372.60
3	2,884,069.35	2,933,756.35
4	2,853,682.25	2,908,679.25
5	2,717,227.31	2,667,845.11
6	3,352,475.19	3,410,045.84
7	2,980,229.80	3,035,574.30
8	3,110,438.00	No Bid
Government Estimate	2,915,225.28	2,941,033.85

Note: The low total bid, i.e. welded or riveted for each bidder, is underscored

Although six out of eight of the above bidders were low on the welded construction, it is somewhat disconcerting to proponents of welding to note that the low bid was for riveted construction. However, it must be realized that the cost of such a dam involves many items in addition to metal work. Any number of factors can be expected to modify the complexion of highly competitive bids and they invariably do. The following table compiled from the itemized bids lists additional data which tend further to indicate the cost trends.

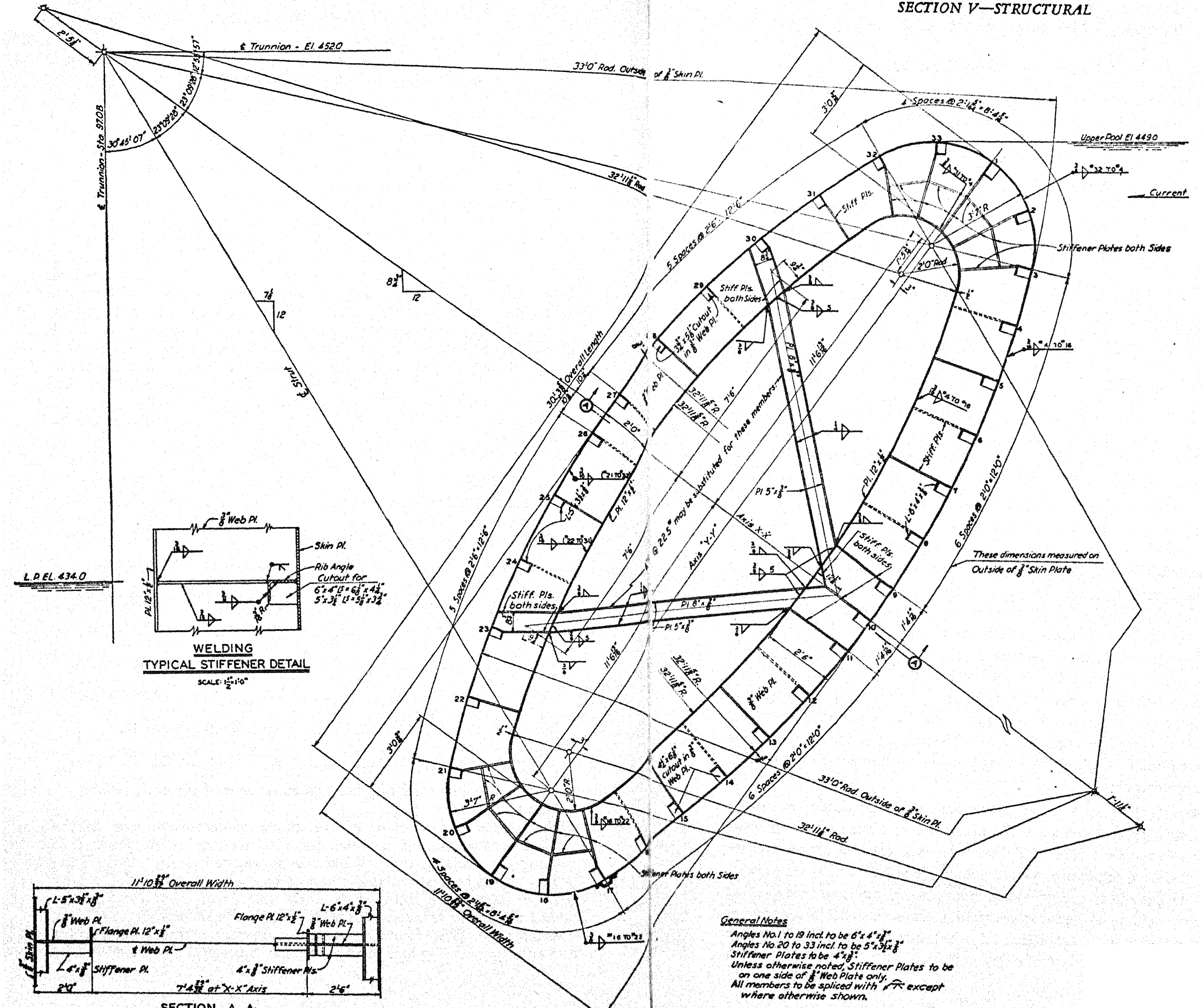


Fig. 7. Tainter gate—section at transverse frame.

Bid Prices for Metal Work Only

Bidder	Welded Bid	Riveted Bid
1	$1,154,349.60	$1,095,280.50
2	1,180,382.20	1,240,320.20
3 (Low Metal Work Bid)	1,070,406.50	1,120,093.50
4	1,128,583.10	1,183,580.10
5	1,271,910.39	1,222,528.19
6	1,215,694.19	1,273,264.84
7	1,166,265.30	1,221,429.80
8	1,177,118.00	No Bid
Government Estimate	1,308,039.08	1,336,452.49

In the case of the metal items as with the total bids, six of eight bids were low for welded construction. In addition, it will be noted the lowest bid for metal work alone was for welded construction although this contractor was not the successful bidder for the entire contract.

Conclusions.—Although it is true that the low bid for the entire contract was for riveted construction, it is believed that an impartial appraisal of the data set forth in the preceding tables clearly indicates that welded fabrication in this type of heavy construction is more economical than riveting. When one also considers superior rigidity, homogeneity, and increased resistance to corrosion, due to the elimination of rivets, it becomes apparent that the use of welded fabrication in river control structures can well be expected to serve taxpayers and investors alike in furnishing better steel structures at lower costs. As a result of the above described experiences, it appears that the relative costs of welded and riveted structures need no longer be determined by soliciting alternate bids. No reason is seen why welded construction can not be specified if considered applicable to the particular structure under consideration.

Although the steel tonnage in this dam is not extraordinary insofar as structures go, the invitation for bids came at a time when competition was keen and a million dollar order was excellent incentive for what is believed to be progressive action. It is hoped that this design and the treatment of the problems related to it may contribute to the art of arc welding in heavy construction. It is felt that the apparent welding consciousness aroused in the industry would make it appear that welding has definitely challenged riveting.

Chapter XIV—Steel Facing for Dams

By R. T. LOGEMAN,
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During the past few years the American Bridge Company, in co-operation with consulting and construction engineers on actual projects, has sponsored a type of construction that has re-opened a field for the use of steel that has been dormant for about 25 years. This new field has to do with the use of steel as the impervious membrane placed on the water face of gravel and rock-fill dams.

This type of construction represents an assembly and application of materials, based on correct engineering design, that offers something both new and economical in dam work. Three prime materials are involved, each placed where most efficient: (a) the fill to take the water pressure; (b) the steel face to form the watertight seal; and (c) the concrete in the foundations and cut-off walls to carry the water seal to bed rock or to the impervious material.

Steel makes an ideal material for dam work. It has strength, is elastic to respond to temperature changes and settlement of the fill, and is 100% impervious. No other material can equal it in these very important features. Other materials may lay some claim to imperviousness, but lack the necessary strength and elasticity to maintain a watertight surface in case the fill settles.

Steel has been, and is being used extensively in the movable parts of dams, but has not been in common use for fixed dams. According to the records, steel, for fixed dams, had its first installation in this country in 1898. This is an all steel dam, known as the Bainbridge Type, which consists, briefly, of steel bents about eight feet apart, with the inclined sides, facing upstream, having a slope of 45 degrees, to which cylindrically-curved plates are riveted, concave to the water. This dam is 46 feet high and 184 feet long, and was built for the Santa Fe Railway at Ash Fork, Arizona. It is still in service, in good condition, with practically no depreciation since its construction, the only maintenance consisting of a coat of paint at intervals of about seven years.

About 1900, flat steel plates, as a facing, were used for the first time on a rock-fill dam near Victor, Colorado, for the Pikes Peak Power Company, now operated by the Southern Colorado Power Company. This dam is about 73 feet high and 405 feet long, 20 feet wide at the top and 148 feet wide at the bottom. The water side is quite steep, being 30 degrees from the vertical. The rock fill was dumped against a dry wall of granite boulders, with the steel plates placed about six inches from the wall, the intervening space being filled with a cushion of sand, gravel, and sedimentary deposit. The entire facing was riveted up with horizontal butt straps and caulked in the same manner as in boiler practice. The plates were punched at the site, are $\frac{1}{2}''$ thick at the bottom, reduced to $\frac{3}{8}''$ about half way up, and to $\frac{1}{4}''$ at the top. Two

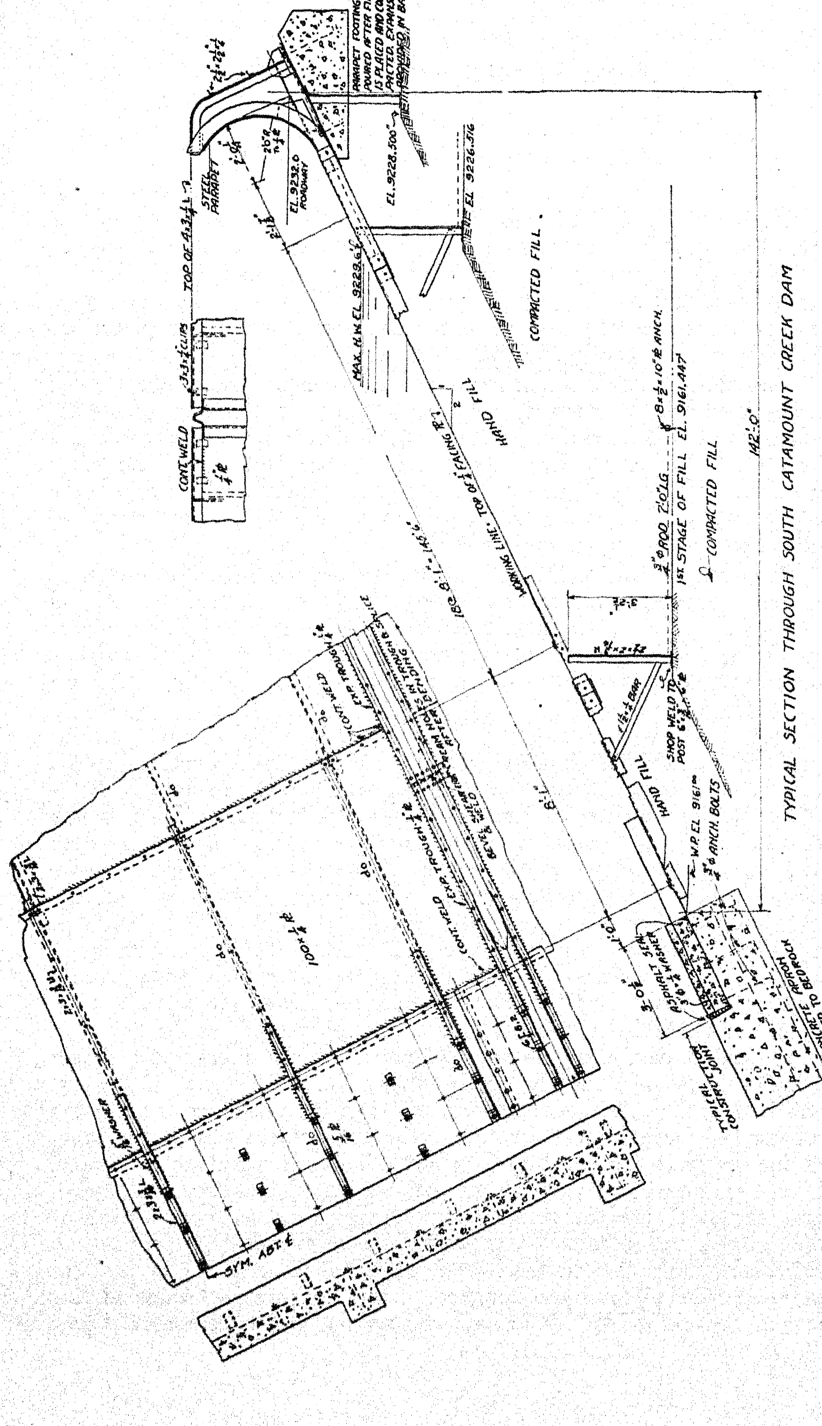

Fig. 1. Design of steel facing for South Catamount Creek Dam, Colorado.

4″ x 5″ x ½″ L's were placed vertically every 15 feet, the 5″ legs projecting into the reservoir, with a 2″ x ⅜″ filler riveted between the extreme outer points. These L's form the expansion joints and at the same time act as stiffeners for the facing. This dam has had severe service due to the water overflowing the top during flood periods and washing out some of the fill, causing a wave-like appearance of the surface to which the plates adjusted themselves without damage or need for repairs. The writer examined this dam a few years ago, at which time some back filling was being made, exposing a portion of the plates for about 15 feet down from the top, showing that the steel work was not painted on the back side, but, nevertheless in excellent condition. The steel facing on the water side was covered with a bituminous paint. This dam has stood up splendidly under the severe tests to which it was subjected and is in condition for many more years of good service.

The second all-steel Bainbridge Type dam, 74 feet high and 464 feet long, was built in 1901 in the Copper Country, at Redridge, Michigan. This dam is also in service today with the steel in good condition.

The third and last all-steel Bainbridge Type dam is known as the Hauser Lake Dam, built for the Montana Power Company, near Helena, Montana. When this dam was put in service in 1907 it was washed out, due to the water undermining the faulty foundations that supported the steel frames. This dam was 81 feet high and 630 feet long.

The foundation failure of the Hauser Lake Dam was used as an exhibit against the use of steel for dam construction, and however unfair, it served to stop further steel dam installations for the ensuing 25 years. Man learns much through failures, and in that sense, the more logical and proper deduction to have made at the time, and which would have rendered a far better service to engineers and the public at large, would have been to have re-affirmed, not once but again and again, the fundamental principle that "A house built on faulty foundations will not stand." During the ensuing 25 years the three steel dams in Arizona, Michigan and Colorado served as silent evidence that steel, if not mistreated, will maintain its real and established value as a construction material. To condemn a material because it cannot do the impossible is just plain folly, and while it may do an injustice for a time, it will not ultimately suppress its correct and economic use.

No structure requires more care and keener engineering judgment in all features of its design than dam work. Whatever the approach to the solution may be, the thought uppermost in the mind of the engineer is that the water must be prevented from breaking the seal or else the integrity of the design is challenged, and failure of the structure may follow. In the gravity-type dam, of masonry or concrete, the structure as a whole is assumed to seal the passage of the water; in the earth-fill type, it is generally an impervious core of clay in the central portion of the fill; while in the gravel and rock-fill type it is either a timber, rubble masonry, concrete or steel facing on the water surface. The factors that have most to do with attacking the water seal are (1) settlement; (2) expansion and contraction; and (3) deterioration.

Much has been and is being recorded in the technical press on dam work, but no specification thus far has been prepared and recognized as a cure-all for the ever-present and impending dam failures. Failures

can and should be avoided with a better understanding of the hazards, and with a greater emphasis on safety. The writer has had occasion to observe at first hand some of the innumerable hazards and recognizes the fact that there is no cure-all for failures, but, in spite of this disturbing situation, is not deterred from recording his ideas of what he considers the proper design of the steel work that will show increased safety and economy in comparison with other materials used as an impervious facing. They are largely the result of the experience gained in the handling of the design, fabrication, and erection of five installations, four in Colorado and one in New Mexico, all pertaining to steel facings on both gravel and rock fill dams.

As a general approach, it can be said that no finished product that will stand the test can be produced unless there is harmony and fusion of all details, and the weakest part made as strong as the whole, as has been so splendidly illustrated in the Deacon's story of the "One Horse Shay," but again, it is one thing to set up such a target and quite another matter to fully realize it.

With the impervious material in direct contact with the water, the entire fill comes into action to resist the sliding and overturning forces, whereas with a core of clay, concrete, or steel placed within the fill, the full resistance of the fill must be offset by the buoyancy effect of the water. One scheme permits a simple means for inspection and repairs; the other does not. Both schemes have been and are used. The central core is protected against shrinkage and temperature variations; the exposed facing is not. These are important differences. In the protected central core, expansion joints are not necessary; in the exposed facing they are both necessary and important. However, in spite of the very important advantages of protection obtainable with the central core, the logical location for the impervious material is in direct contact with the water surface, where it is accessible to inspection and repairs, and where the full resistance of the fill can be utilized, but this means a type of facing that can and will withstand the greater variations of shrinkage and temperature. With equal resistance in the fill to the water pressure, equal water-tightness in the facing, and equal percolation rates, the quantity of fill can be reduced from 25% to 50% and more with the impervious facing in contact with the water.

Regarding the makeup and arrangement of the fill itself, there is a wide variation of opinion and practice. Advocates of the "Hydraulic Principle" "construct one impervious surface and build the rest of the structure to support that surface, and if this surface should not be water-tight, making it as nearly so as possible, in order that seepage or leakage will not be allowed to accumulate pressure against some other surface, or do other damage in getting away." Following this principle means careful grading of the fill from an impervious composition at the water surface, to a pervious composition through the balance of the fill. On the other hand, there are advocates of a uniform fill, with a constant density and compaction, the main purpose of the fill being to support and maintain the impervious face. Regardless of the type of the impervious face, or makeup of fill, the integrity of both must be maintained under settlement, shrinkage, temperature and deterioration.

Steel facings can be placed either after the fill is completed or in

tiers on steel horses or bents in conjunction with and just in advance of the fill. Placing the steel facing after the fill is completed, or in case of a high dam, after a considerable portion of the fill is ready for the facing, will slow up the progress and call for a careful finish of the fill so as to prevent loose particles from rolling down and wedging under the steel facing during construction. This is particularly true where the steel facing is placed directly against a rough curtain wall of rubble masonry, a condition that can be overcome by dressing the rough masonry with a finished coat of concrete or mortar.

When laid against a rubble wall, the plates are anchored to the wall with a special type anchor that permits movement of the plates in all directions due to temperature changes, and in case of a steep slope, stiffeners are used to prevent the plates from sliding down the slope. These are features that should not be overlooked, because, unless securely anchored or stiffened, the plates, during a temperature increase, in other words, while expanding, will naturally tend to work downhill more readily than against gravity.

For the ordinary gravel or rockfill dam, the practicable and economical method is to place the facing plates in advance, so that they also act as forms for the finished fill. Starting at the base of the cut-off wall, the first tier of plates is placed on and connected to the steel horses, which are spaced about five feet apart, and where possible, the entire tier is placed and connected to both sides of the canyon cut-off walls. This insures proper assembly and fit as the erection progresses. The facing plates are securely bolted to the horses, and the horses in turn are anchored into the rolled and compacted portion of the fill. The horses are also connected to the cut-off plates, while the plates extend into the concrete and are anchored with rods extending through and bolted thereto with nuts on both sides. This precaution should be taken to prevent breaking the bond between the concrete and steel plates, as it insures a better water seal.

As soon as the first stage of the rolled and compacted fill reaches the height of the first tier of plates, the second tier of plates is placed and connected to the first tier of plates. The rolled fill comes within about 2½ feet of the underneath surface of the plates, which is as close as the machine rollers can work, and also allows the necessary working space for erecting and painting. This space is later hand-filled and tamped. In this manner tier after tier is erected and finished, and progresses as fast as the filling can be placed.

The size and thickness of plates and chemical properties are matters that depend upon the particular project; among other things, transportation facilities, quality of water, and height of dam. In general, 100 inches is an economical width of plate, of from ¼ to ½ inch thickness, with the plates extending full length and unspliced between expansion joints, spaced 20 to 30 feet apart.

Perhaps the most important feature in the steel facing is the assembly and welding so as to obtain both strength and water tightness. All connections and splices should be made so as to resist any moment action that may be brought about either by settlement of the fill, or any extreme temperature stress. This cannot be done as economically and with the same degree of water tightness by the old method of riveting and caulk-

ing as by the more modern method of welding. With rivets it would require from three to four rows, closely spaced, on both sides of the splice, to develop the full net strength of the plate, and even on the assumption of sound and tight rivets, there would be no assurance that the caulking would hold if the plates were subjected to severe bending and moment action due to any settlement of the fill. With present day technique, a welded splice can be made as strong as the parent metal, and also maintain the desired water tightness. This combination has decided economical advantages.

The plates are arranged for lap joints and down welding, punched at the shop along all four sides at about 12 inch centers, and with about a two-inch edge distance. Punching the plates permits using them as they come from the rolling mills, without the necessity of expensive edge planing that would be required for proper and safe butt welding, and also results in a quick and accurate assembly in the field. Bolts are used for all the joints with the nuts placed on the exposed surface. The bolts, with the liberal two-inch edge distance, also act to relieve the welds from any moment stress in the lap joints, which are welded only on the exposed surface. There is no objection or particular difficulty in welding on both sides of the joints except for the added expense, and in important installations this added expense may, in the light of added insurance for safety, be a worth-while expenditure.

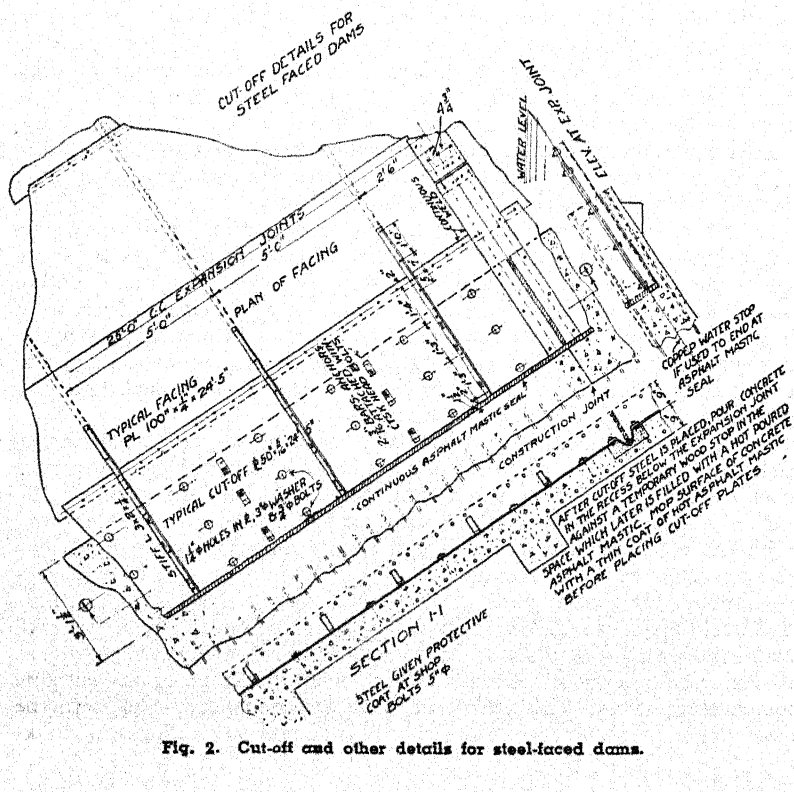

Fig. 2. Cut-off and other details for steel-faced dams.

For the expansion joints, which are generally U-shaped, a butt weld is used because it avoids, as would be the case in a lap weld, either an expensive taper or an expensive crimp. The ends are bevel-planed for welding and wrapped with a splice plate that is formed to fit accurately around the expansion joint, and also acts as a backing plate for the butt welds.

The primary function of the U-shaped expansion joints is to provide for contraction, while the expansion forces produce slight ripples in the plates without the slightest injury, but, if desired, the flexible steel plates can be reinforced with stiffeners so as to take compression as well as tension, in which case the expansion joints will act like an accordion and function in both compression and tension.

All steel should be clean and protected with a carefully applied coating before leaving the shop. Such a coating should protect the steel during transportation and erection, but not prevent the making of good welds, as would be the case with a painted surface. One or two coats of good paint are applied after the welding is completed. The plates should come in close contact and be drawn up tight with permanent assembly bolts in order to insure the proper setting for welding.

All welding should be done by the electric arc process. Coated rods should be used because shielding the arc produces a better and 25% stronger weld than can be obtained with bare rods and the unshielded arc. For the lap weld, the size of the fillet leg should be slightly increased and made to a gradual slope so as to obtain a more uniform distribution of the stress. All welds are full strength and continuous, with nuts seal-welded to the plates and threads welded to the nuts, so that the finished steel surface makes an absolutely water-tight cover. In addition to proper welding equipment and procedure, only experienced welders should be used.

Where the steel facing enters the concrete cut-off foundations along the bottom and along the canyon walls, the expansion joints should continue into the concrete so as to avoid blocking the action and movement due to expansion or contraction. To avoid cracks in the concrete cut-off that encloses the steel, the concrete should be thoroughly reinforced and anchored to the steel, and provided with construction joints, filled with asphalt mastic, in the same plane with the expansion joints in the steel facing. As a further precaution, the finished and exposed portion of the concrete cut-off can be covered with a blanket of fill which will absorb and cushion the effect of the temperature on the concrete.

Along the crest, where the entire temperature range must be met without any restrictions, a steel parapet, with expansion joints, serves as a practical and neat finish.

A survey of the completed steel facing, in accordance with the foregoing description, discloses a continuous, water-tight membrane, strong and elastic in both tension and compression. It is self-contained, and at the same time anchored to the fill itself with sufficient flexibility in the anchorage to adjust itself without rupture to any ordinary settlement. This makes for an ideal impervious surface.

Fig. 1 shows the design of the steel facing for the South Catamount Creek Dam for the City of Colorado Springs, which was completed and dedicated on September 12, 1937. It embodies all the latest features in

this type of construction, except that the expansion joints did not extend into the cut-off walls.

Even though steel, when restrained from moving, can absorb temperature stresses as an internal stress, and even though it requires a temperature of 150 degrees before the stress in the steel will approach its elastic limit, it is not good construction to block the movement. The better and safer construction is to extend the expansion joints the full length of the steel facing to the end or bottom of the cut-off plates. For that reason the detail shown on Fig. 2 entitled "Cut-off Details for Steel Faced Dams," made by the writer during June of 1937, shows the improved construction for future installations. Reference to same shows, among other features: (a) the steel anchored to the concrete; (b) the expansion joint extending to the bottom of the steel work; and (c) the mastic seal between the steel and concrete. In addition to improved and safer construction, there follows also a saving of some rather expensive shop work in the fabrication of the expansion joints.

Experience gained from our records, based on average conditions, shows that the cost of a riveted and caulked facing will be about 22½% greater than a bolted and welded facing.

Entirely apart from any merit that a steel facing may have, and also apart from the very definite economy of welding and the opportunity for a large saving in the fill, referred to in the foregoing, steel must be able to establish its claim on a cost basis that will not make its use prohibitive in comparison with any other acceptable material. The ever important matter of comparative costs should not, however, be the one prevailing consideration in the decision of the type of structure to build, without, also, a careful weighing of such equally important factors as (1) Safety of Structure; (2) Maintenance, and (3) Length of Life. No general formula can be devised to cover all features, but one underlying guide for the engineer should be never to temporize with safety because that is not economy. In comparing a steel facing with (1) clay; (2) timber; (3) rubble masonry; or (4) concrete—all of which have been and are being used—the engineer should recognize their limitations as well as their merits. All are useful building materials in dam work but should not be improperly used.

Clay, used as the central impervious core in earth fill dams, requires an enlarged fill to maintain the core in position, and when used as an impervious blanket in rock-fill dams near the water surface requires, in addition, a protecting material against wave action and scour. For low dams, where the ratio of facing to fill costs is greatest, the central impervious core is economical, but for higher dams, bearing in mind that the facing increases as the height and the fill as the square, there is a very rapid increase in cost and a corresponding decrease in economy.

An outstanding illustration of the size and cost of fill in an earth-fill dam with the central core is seen in the present construction of the Fort Peck Dam in Wyoming. This dam is 242 feet high and 2875 feet wide at the base, a ratio of about 1 to 12. An interesting illustration of the size and cost of fill in a rock-fill dam with an impervious blanket can be seen in the recently completed San Gabriel Dam No. 1 for the Los Angeles Flood Control District in California. This dam is about 370 feet high and the original design called for a reinforced concrete face,

with a width of fill at the base of 900 feet. The failure of San Gabriel Dam No. 2, a somewhat smaller dam located a few miles up the same canyon, and of similar design, resulted in discarding the concrete face for San Gabriel Dam No. 1, using instead the impervious blanket within the fill, and increasing the original width of fill at the base from 900 feet to 2000 feet.

Timber, as a facing material, has reasonable strength in both tension and compression, can be made reasonably water-tight, is economical, especially in locations close to a timber market, and will give good service if kept constantly under water, but subject to rapid deterioration if alternately wet and dry. It is an excellent material for temporary dams, or used as a temporary facing for later replacement by a more permanent facing after the fill has stopped settling.

Rubble masonry, carefully laid in cement mortar, can also be made reasonably tight if the water pressure is not too great, but its use is more as an intermediary, non-settling safety layer, placed between a more or less settling fill, and a facing of concrete or steel that should be protected against settlement.

Concrete, as a facing material, was first used in this country about 30 years ago, which is about 10 years after steel was first used for both an all-steel dam and as a facing for a rock-fill dam. As a building material, concrete has had a very rapid growth, but it, too, like every other building material, including steel, has its limitations. Steel and concrete have nearly equal coefficients of expansion, and, therefore, for all practicable purposes the two materials are subject to the same dimensional changes because of temperature. Dealing with large, unprotected surfaces, and a wide range of temperature, as is the case in dam work, the movement of the facing, both in contracting and in expanding, becomes a very important matter for proper treatment. Any facing built without proper provision for such movement, should, in that case, be made up of materials that possess sufficient strength and elasticity to absorb the temperature forces in internal stress without surpassing the margin of safety or impairing its property as an impervious material.

With expansion joints designed to absorb temperature stresses, the entire strength of facing can be counted upon to resist the direct loading stresses resulting from a settlement of the fill. While any extreme temperature variation should be provided for, it would, on the other hand, be both futile and irrational to attempt a design of facing that would stand up under an extreme settlement. What thickness of plate to use in the case of a steel facing, and what thickness of slab and amount of reinforcement to use in the case of a concrete facing, are questions that are a challenge to the best judgment of the engineer. There is no guide to use except judgment and experience. Some concrete facings have been used without any reinforcement, and, from all reports, giving good service, but such construction is the exception to the general practice, and can be justified only where there is little variation in temperature and not much settlement. The general rule has been to make the slab thickness some ratio of the height of dam, approximately 1% or more of the height, and the reinforcement some ratio of the cross-sectional slab area, approximately 0.5% or more.

As a supplementary aid in arriving at the correct design and a comparison of a steel facing with a concrete facing, recourse might be made to a comparison on a strength basis, similar to that used in comparing designs of bridges and buildings, and using the additional light of such a comparison, together with any and all other related factors, as a guide in the final selection of the type of structure most suitable and economical for any particular installation. Since the critical test on the facing from both temperature and settlement is one of tension rather than compression, and on the generally accepted basis of the reinforcing bars taking the entire tensile stress, a concrete facing of equal strength to a steel facing, will require two sets of rods at right angles to each other, each set of equal strength, and each set equal to the area of the steel plate.

Instead of taking a hypothetical design to illustrate a comparison on strength ratios, the writer makes reference to an actual installation in the State of Colorado, where such a comparison was established from competitive bidding, a basis that should result in a better and more reliable comparison than might be the case with an estimate. This installation, for which a 1/4 inch copper-bearing steel facing was used, comprised about 93,000 square feet of facing, laid on a compacted gravel-fill having a slope of two feet horizontal to one foot vertical. The proposed concrete facing consisted of a slab of 10 inch average thickness, reinforced both ways, with two 1/2 inch round rods, one of them near the top and the other near the bottom, spaced an average of 9 1/2 inches apart. The slab thickness was equivalent to about 1.42% of the height, and the reinforcement to about 0.42% of the sectional area; on a strength ratio the concrete facing was equal to about 1/6 of that of the steel facing; while a cost comparison showed a 3% economy in the steel facing.

No design was made and no bids were taken on a concrete slab that would compare with the steel facing on an equal strength basis, and therefore, in order to establish such a comparison, it becomes necessary to do so on the basis of an estimate. For this purpose the same 10-inch thickness of slab and the same number and 9 1/2 inch spacing of rods is taken, so that the cost of the concrete and placing of rods remains, for all practical purposes, a constant, resulting in confining the increased cost of the stronger slab to the delivered cost of the added reinforcing material. To express the increased cost on a percentage basis, it then merely is necessary to establish the ratio of the delivered cost of the reinforcing rods to the finished cost of the concrete facing, and adjusting for the 3% which represents the initial difference in cost between the steel facing and the concrete facing which forms the basis for this comparison.

For the concrete facing with only 1/6 the strength of the steel facing, this ratio was found to be about 12 1/2% for the delivered cost of the bars, while the remaining 87 1/2% covered the constant costs of placing the bars, and the concrete.

With the foregoing factors we can write the following summary, giving the increased cost of a ten inch concrete facing over a 1/4 inch steel facing:

Initial increase		3.0%
Cost based on plate area—6 x 12.5%	75.0%	
Cost based on 1/6 plate area	12.5%	
Increased cost between respective Concrete facings	= 62.5%	62.5%
Increased cost with reference to Steel facing = 3% of	62.5%	1.9%
Total increased cost =		67.4%

While these comparative costs apply specifically to a ¼ inch steel facing and a 10 inch concrete facing, and subject to change with a change in design, they nevertheless are not far from average conditions.

When a steel facing is to be used on a masonry or concrete dam with a vertical surface, it becomes necessary to give special attention to both vertical and horizontal expansion, because, unless there is freedom of movement, a drop in temperature would subject the steel facing to internal stress, and call for very strong connections to the masonry or concrete wall. Temperature variations are a matter of assumption, based on the best information available for any particular location, but cannot be guaranteed or controlled, and therefore, it is best to err on the side of safety and provide for an extreme variation, or else work out a design which will avoid internal stress conditions. To realize the full significance of this, it is merely necessary to bear in mind that in a restrained condition a one-degree change in temperature means an internal stress of about 200 pounds per square inch, on which basis a 100-degree change, which is not an extreme case, would, with a ¼-inch plate, result in a stress of 5000 pounds per linear inch, and, with supports at say five feet apart, a reaction of 300,000 pounds on any single support. This illustration is given to show a situation that should be avoided.

The writer had occasion to investigate and study this somewhat perplexing situation during the past year, in connection with the rehabilitation of a 26-year-old vertical face concrete dam, and realized the handicap engineers were under because no practicable expansion joint has been, and perhaps never will be, devised that will function in all directions. After a study of various schemes the writer finally devised a rather simple and practicable design whereby expansion and contraction, both longitudinal and transverse, can be provided, and internal stress avoided; in other words, a design that provides for a two-way expansion and contraction.

This is accomplished, as shown in Fig. 3, by using a U-shaped expansion joint to provide for movement in the longitudinal direction, and slightly dishing the expansion joints and plates to provide for movement in the vertical direction. The expansion joints are dished at the shop, but the flexible plates are dished in the field by means of dished erection angles that are bolted to the plates prior to placing them in position, thereby maintaining the correct dish while making the permanent connection to the supports. The steel facing, properly dished and held to the supports, is located from six inches to twelve inches from the concrete surface, which space is filled with a cushion of concrete as the erection progresses. After the welding is completed and the concrete

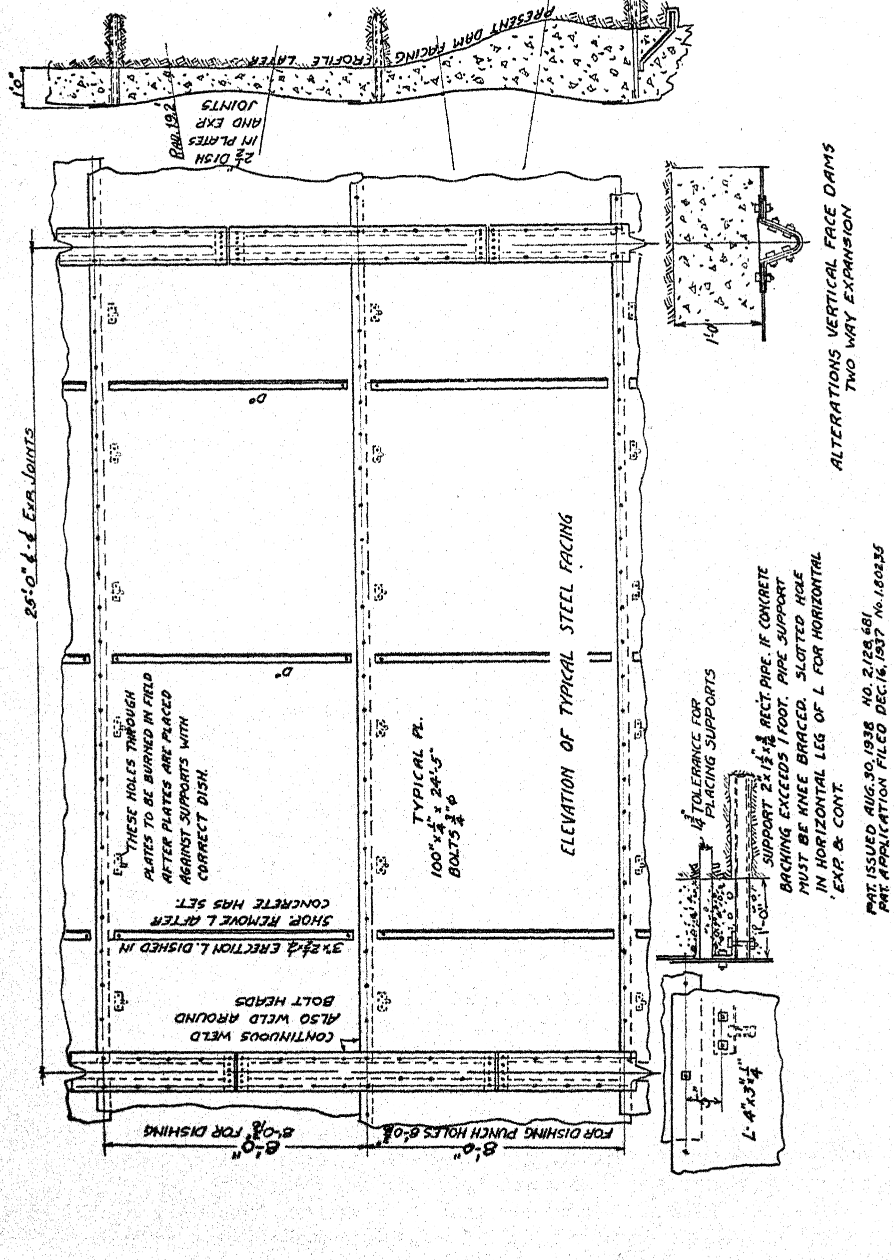

Fig. 3. Design which provides for a two-way expansion and contraction.

filler has set, the dished erection angles are removed and used on other parts of the work. This design provides a rigid and positive connection of the steel facing to the vertical wall, permits freedom of movement, and avoids internal stress. (An application for a patent on this design was filed in December, 1937 and is, therefore, pending.)

To estimate "the gross savings to industry through the general adoption of the design described," would at best be very tentative, but, even so, it might be suggestive of an approximation to the ultimate answer. As an approach to this question the writer refers to an article and editorial in a technical magazine of July 16, 1936, giving the results of a six-year inspection of existing dams in the State of California. Over 900 dams were examined and reviewed as to safety, with the rather disturbing, but perhaps to be expected, result that "Not more than one-third of the dams could be pronounced satisfactory immediately, one-third required further consideration, and one-third needed repairs." 588 dams under state jurisdiction are stated as representing a capital investment of about $200,000,000. This is equivalent to about $340,000. per dam, and for the 950 dams examined would represent a capital investment of about $325,000,000.

The saving in capital investment would be made up in: (1), a reduction in the fill, which, as stated, may be between 25% and 50% and more; (2) a steel facing of the welded type, which, as illustrated, shows a 22½% preference over the riveted type; and (3) a welded facing over a concrete facing with sufficient reinforcement to compare on a strength basis, which, as illustrated for a ¼ inch steel facing and a 10 inch concrete facing, means a difference of 67.4%.

To express the combined saving from these three items means the assumption of average relations, between facing and fill with respect to the total cost of the dam, which may be subject to rather wide variations in any specific installation. For instance, the facing varies, approximately, in direct relation to the height, whereas the fill varies, approximately, as the square, and therefore, any expressed saving must be based on the height of dam. However, in spite of this complex relation, it is possible to establish an expression based on average conditions, and applying a correction factor or key for any variations from the assumed conditions.

For such purpose the following average assumptions form the basis of the expressed saving; (1) the combined cost of facing and fill for the most economical type dam equals 45% of the total, the remaining 55% not entering into the problem and covering the cost of excavation, cut-off foundations, engineering and miscellaneous items; (2) from a study of comparative designs, it was found that for a dam 45 feet high the ratio of cost of facing to fill is approximately one to one; at 90 feet a ratio of one to two; at 135 feet a ratio of one to three; and at 180 feet a ratio of one to four. In other words, as the dam height increases the cost of facing is decreasing while the fill is increasing, the combined cost of the two, however, remaining at 45% of the total; (3) the saving in fill is confined to an increase of only 25% in the width of base; (4) the saving in welding over riveting is taken at 22½%; and (5) the saving in a steel facing over a concrete facing is taken at 67.4%.

From these assumptions and relations, a simple calculation will give the following results:

Saving in Capital Investment for dam 45 feet high = about 25.7%
Saving in Capital Investment for dam 90 feet high = about 21.0%
Saving in Capital Investment for dam 135 feet high = about 18.5%
Saving in Capital Investment for dam 180 feet high = about 17.0%

To determine the saving for industry at large would require a survey such as was made by the State of California, in the absence of which the answer becomes one of conjecture. However, with $340,000 as an average capital investment per dam, a 20% saving will sum up to an item sufficiently large and well worth considering in future capital investments. In addition, there is the very important advantage of increased strength and safety, with a background of 40 years' service of existing dams that are still functioning and in splendid condition.

Conclusions.—1. As a facing material, steel is strong in both tension and compression, and intrinsically impervious.

2. With an impervious facing in direct contact with the water surface, a substantial saving is possible in the fill, the entire mass, without buoyancy deduction, resisting the water pressure.

3. With the impervious facing in direct contact with the water surface, it is accessible for inspection and repairs.

4. A steel facing forms a continuous water-tight membrane, strong and elastic, self-contained and at the same time anchored to the fill with sufficient flexibility to adjust itself to temperature variations and any ordinary settlement.

5. From the early installations of 40 years ago, steel, as an impervious facing, has evidenced its claim as a useful and economical material.

6. A steel facing of the bolted and welded type shows very definite economies over the riveted and caulked type.

7. With a vertical steel facing, rigidly connected to a concrete or masonry surface, a two-way expansion gives freedom of movement in horizontal and vertical directions, and avoids internal stresses.

8. Considering increased strength and safety, a steel facing in direct contact with the water surface, with allowable reduction in fill, shows a capital investment saving per average dam of about 20%.

SECTION VI

FURNITURE AND FIXTURES

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SECTION VI
FURNITURE AND FIXTURES

Chapter I—The Arc Welded Steel Frame Lecture Room Chair

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The standardization of equipment is probably one of the most perplexing problems which confronts the construction and repair department of any large college or university. Naturally this department, looking toward minimizing the cost of repairs and replacement, leans to over-standardization. With all of the stress being laid in this direction, however, there is little danger of its going too far. This is due to the present high rate of improvement in college equipment in general. There is always an undeclared war waged against this standardization by all employees of the institution whose lot it is to have to use the equipment.

For this opposition there is naturally a number of reasons, some of which may be listed as follows:

1. Desire for variety in equipment where appearance is a large item.
2. Difference in taste.
3. Difference in systems used in various departments.
4. Pressure brought to bear by super-salesmen.
5. Hope of replacing an unsatisfactory article with one of superior quality.

The first four items above need no discussion. The last is one which will stand considerable study.

The writer has made a survey of one of the nation's large undergraduate colleges, referred to hereinafter as the college. This survey revealed a tendency toward variety in equipment, beyond the wildest dream. An interview with the heads of departments brought to light the fact that only a negligible per cent of this extreme variation in types was due to either pure desire for variety or difference in taste. The driving force behind this non-standardization is the hope of finding equipment that will stand up under daily use. Of course no consideration is here given to articles which must differ due to different systems used in various departments.

Leading, in type variation, all other pieces of college equipment, was found, the lecture room chair. If this were an article having a variety of uses we might lay the cause of this finding to the importance of the particular use in each department. But the lecture room chair is a single-purpose fixture. The utility requirements are very simple. It must provide a comfortable place to sit, a place to lay the note book positioned for writing, and a place for the hat and books. This would appear to be the easiest piece of equipment in the college to standardize. More than half of the chairs in the college nearly meet all of these requirements, and the remainder, all but the last item. Then it is not for this reason that

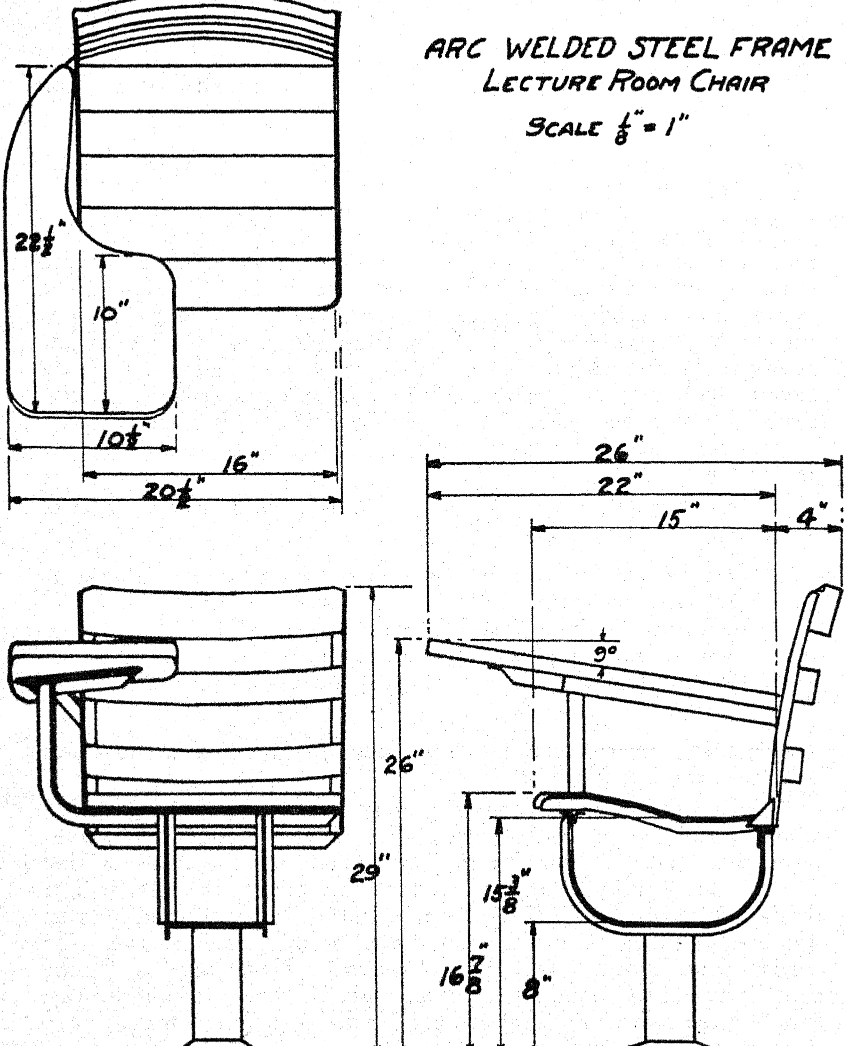

Fig. 1. Arc welded steel frame lecture room chair. (See photo of chair in Fig. 7).

each order for chairs brings a shipment of new design and construction. It is a search for a chair that will meet important requirements other than utility.

It is the purpose of this paper to describe and show the construction details of an all-steel frame lecture room chair designed, built, and tested to more nearly meet all requirements than any chair that the writer has been able to find on the market. The design of this chair was made after an extended study of all those important features which appear to have

been generally neglected in chair design. This study was made from the standpoint of:

First; The student who has to use the chairs.
Second; The instructor who must contend with them.
Third; The business manager of the college.
Fourth; The manufacturer.

It was found that any chair that was correct in size and shape had all utility requirements, and was in good condition, was satisfactory to the student. A little more than fifty per cent of the chairs in the college met requirements as to size, shape, and utility. Three to six years of age, depending on the amount of use, was necessary, on the average, to cause the condition of the chair to be a source of annoyance to the student. Chairs that were apparently of the best quality and construction became loose jointed and noisy, or both.

To the instructor, this long period of time between the first squeak under the indifferent ever-shifting human overload and the time of necessary repair or replacement is a never-ending source of trouble. As was stated above, the instructor looks for a chair that will stand up under daily use.

The business manager's interest in the matter lies primarily in the cost. He of course wants a chair that will reduce to a minimum, initial cost, cost of repair, and even apparent minor costs, such as janitor's time sweeping, cleaning, etc.

The manufacturer is naturally interested in the cost of production, salability of the product, and the size and location of the market.

In the college were found, in round numbers, 1,600 lecture room chairs with tablet arm. These included 47 different designs and the following types of construction:

Chair A. All wood with four legs.
Chair B. Wood with steel bracing, four legs.
Chair C. Wood bench type, four seats together.
Chair D. Pressed steel frame, riveted, four legs, wood seat and tablet arm.
Chair E. Bolted steel frame, cast iron single column base, wood seat and tablet arm.

A desirability rating of the following requirements was made on each of these types:

1. Appearance.
2. Comfort and utility.
3. Initial cost.
4. Durability, or time before necessary repair.
5. Time between repairs.
6. Cost of repairs.
7. Janitor cost, cleaning, etc.

It was found that the first requirement could be met in any of the types and was a function of the initial cost. Type C rated highest in initial cost economy, but was low in all other requirements. Chair D showed the greatest durability and time between repairs, but was ex-

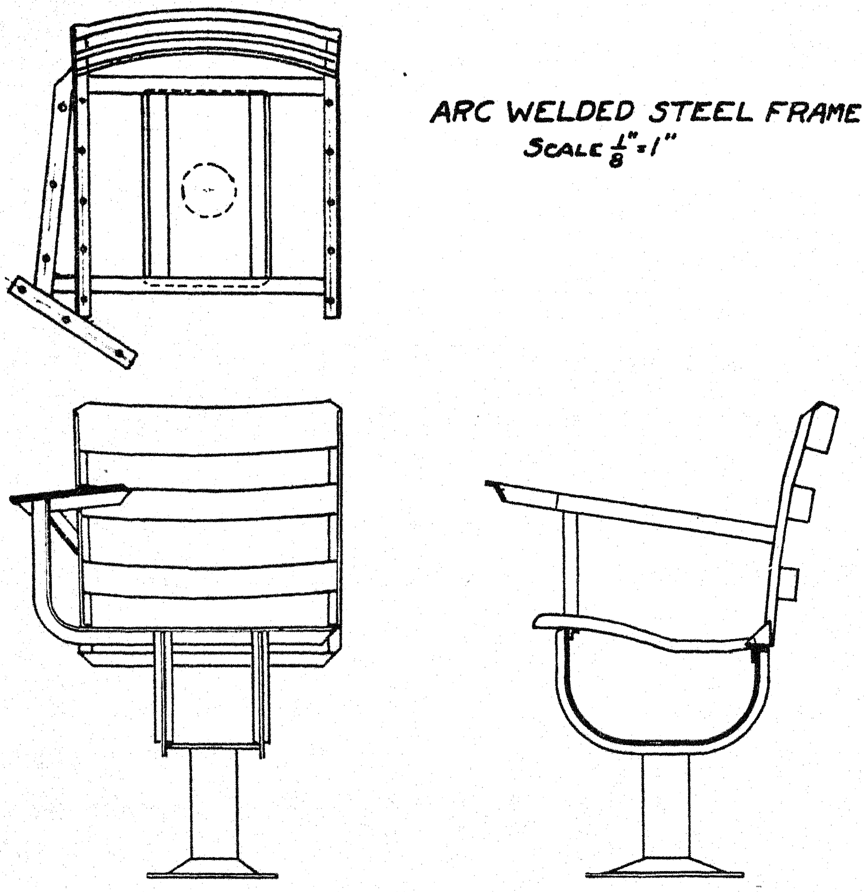

Fig. 2. Arc welded steel frame of chair.

pensive to repair. E was found to have the best rating on janitor cost, but worst on durability, utility, and comfort. None of the chairs showed, to a high degree, all desirable qualifications. All data along this line pointed to the fact that the use of steel in construction raised the desirability rating in the majority of cases.

Solution.—As an experiment, the writer designed and built sixty chairs, the frames of which were entirely of arc welded bar size structural shaped steel. The tablet arm and seat were of oak. The design stressed the one feature, durability. These chairs were placed in a class room which, in addition to its normal use, was used for the football team meetings. They have been given a severe test for four years, and are still in perfect condition, one hundred per cent. This chair has been neither sold on the market nor generally used, and therefore the time test may

not be conclusive evidence of its superiority. However none of the five types listed above, which include 47 different designs, have stood up one hundred per cent for even half that period of time. The nearest approach in durability was found in the all-steel frame riveted chair. Advantages of the arc welded frame over this type are shown in subsequent paragraphs.

After the four-year test on these chairs was made, the writer endeavored to design a chair which adheres to the construction details of the tested chair and, at the same time, meets all of the other requirements listed above.

Description.—The arc welded steel frame lecture room chair, referred to hereinafter as the new design, is described briefly as follows:

Fig. 1 shows the assembled unit and Fig. 2, the steel frame without the wood.

The frame is made in one unit by the arc welding of standard steel sections. The base is of the single-column type made up of parts 1, 2, and 3, Fig. 3. The seat is supported by two cross members which are connected with the column cap by U-shaped tee sections, part 4, Fig. 4. The front cross member, part 5, Fig. 4, is bent upward to support one end of the angle iron to which the tablet arm is screwed. The sides of the seat and back are continuous and are of bar size angle, part 6, Fig. 5. The back rests are round-edge flat steel, crimped and curved, shown as parts 7 and 8, Fig. 5. Angles are used for the tablet arm support.

The seat and tablet arm are of rift-sawed oak. The seat is made of five pieces, parts 9 and 10, Fig. 6. These parts are fitted as shown in Fig. 1 and fastened to part 6, Fig. 5, with screws. The tablet arm is of one piece, Part 11, Fig. 6. It is held in position by screws.

Appearance.—It is a recognized fact that, where a large number of like articles is grouped together, simplicity in design is a great aid in presenting a good appearance. This feature is stressed in the arc welded steel frame chair, as shown in the photograph, Fig. 7. There is a minimum of parts due to the fact that no bracing is required. The properly welded joint at any angle will carry practically the same cantilever load as the straight beam.

The riveted steel frame, which more nearly approaches the arc welded in durability, requires cross bracing on practically all corners to take care of non-rigid joints. This tends to emphasize the weakness in the joints, to add to the confusion of small parts, and to detract generally from the appearance. These small flat bracing members become easily bent, thus making an otherwise sound chair appear dilapidated.

The wood chairs in some designs are satisfactory in appearance as long as they last.

Utility and Comfort.—The idea that it is undesirable to make a student too comfortable in class, for fear that he will sleep, has apparently been taken too seriously by some furniture designers. It is the opinion of the best instructors that, if the lecturer must depend upon the chair to keep the student awake, there is something wrong with the lecture. All industry agrees that the best work is done under the best conditions.

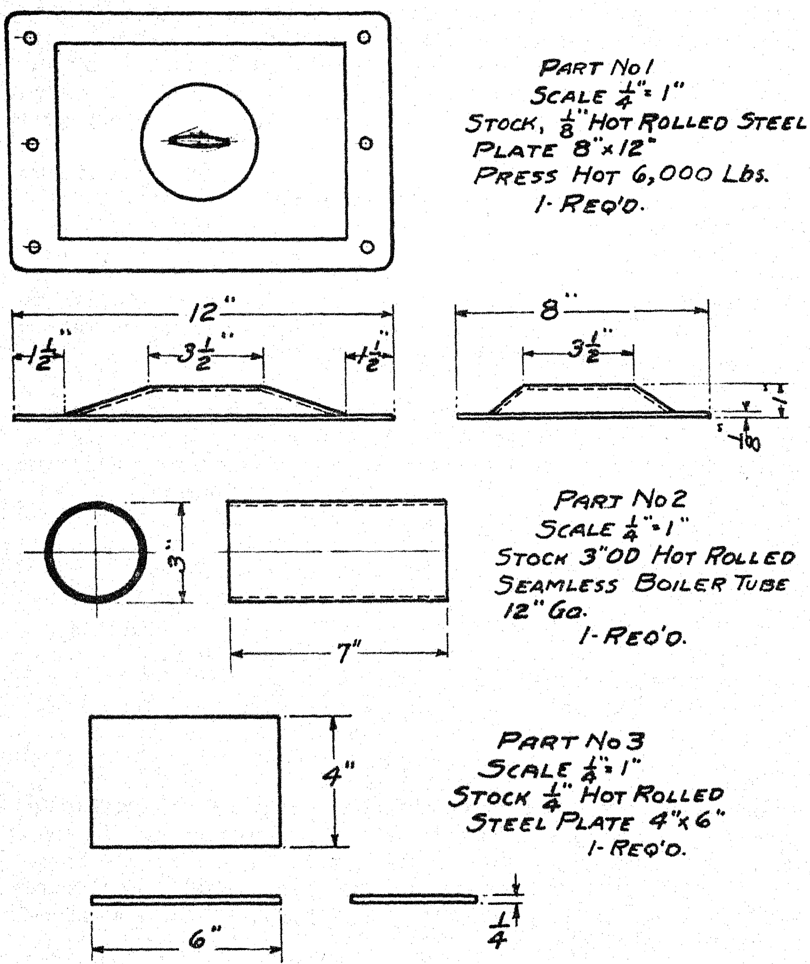

Fig. 3. Parts comprising base of chair.

The shape of the chair, here described, is designed to permit the student to forget his physical position and concentrate on mental work.

A small space is provided under the chair for hat and books. This space is made adequate for this purpose but small enough not to accumulate trash.

Cost.—It was not the primary aim in the design of the steel frame chair to reduce the cost of manufacture, thereby lowering the initial cost to the buyer. Stress was laid on raising the value of the finished product, by making it meet, to a high degree, all utility requirements and on reducing the overall cost, including initial and service.

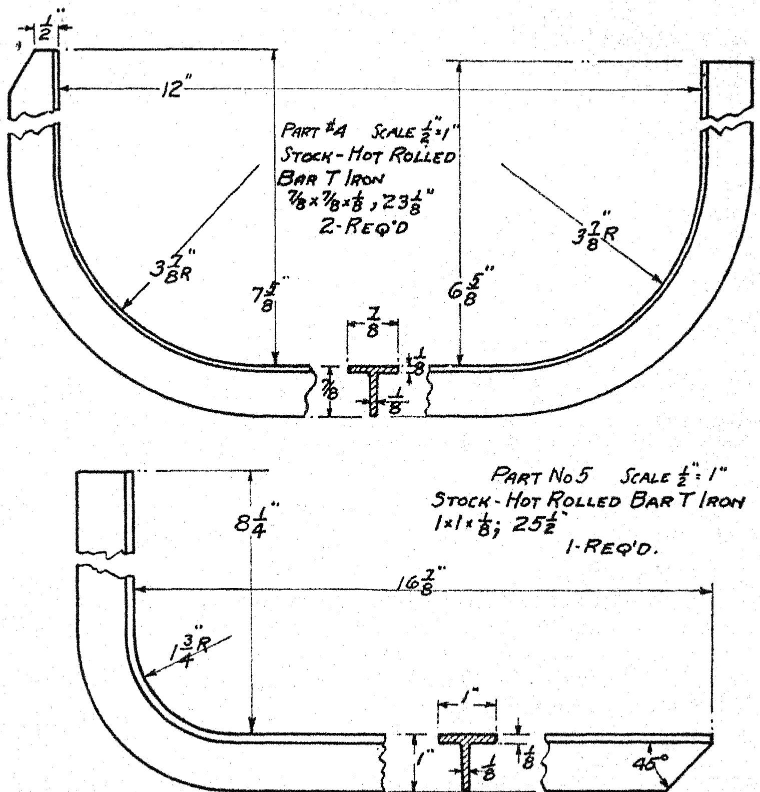

Fig. 4. U-shaped tee sections (part No. 4) connect two cross members, supporting seat, with column cap; and, (part No. 5) support one end of angle iron holding tablet arm.

There is a large number of makes, designs, and types of chairs on the market. It is therefore impossible to compare the arc welded chair with each design separately. Comparison is here made of each feature with the chair that shows the highest rate of desirability in that feature.

The cost of manufacture of the new design is shown in the summary cost table below. These figures were taken from the data on actual construction. This work was done with machines and equipment available to the writer. Comparison of cost, as made with other types of design, is made assuming the same general proportionate value of equipment.

COST SUMMARY

Item	Materials (Direct)	Materials (Indirect)	Labor (Direct)	Labor (Indirect)	Power	Total
Steel (cut, formed)	$121.34	$ .32*	$12.04	$	$	$ ....
Set up	....	......	....	2.70	......	....
Machine	....	......	....	......	2.20	....
Steel parts	$121.34	$ .32	$12.04	$2.70	$2.20	$138.60

*Furnace fuel.

Wood (cut, shaped)	$ 20.13	$	$ 3.32	$	$	$ ....
Set up	....	......	....	2.95	......	....
Machine	....	......	....	......	1.37	....
Wood parts	$ 20.13	$	$ 3.32	$2.95	$1.37	$ 27.77
Assembly						
Set up jigs	$.........	$......	$.......	$ .26	$......	$.........
Set up parts	....	......	10.12	......	......	....
Weld	12.00	......	31.75	......	1.95	....
Final	3.88**	......	3.40	......	......	....
Assembly	$ 15.88	$	$45.27	$ .26	$1.95	$ 63.36
Finish	$ 24.83	$	$16.40	$	$	$ 41.23
Cost per 100 units	$182.18	$ .32	$77.03	$5.91	$5.52	$270.96

**Screws.

The total prime cost on the new design is found to be approximately $271.00 per 100 units. This cost is divided as follows:

1. Steel frame
   - Parts. (Materials, labor, machine cost) $138.60
   - Assembly. (Set up, weld) 56.08
   - Total $194.68
2. Wood seat and tablet arm.
   - Labor, materials, machine cost, assembly................$ 35.05
3. Finishing.
   - Labor, materials 41.23

Prime cost $270.96
Per chair ....$ 2.71

By similar method of calculating material and labor cost, using similar types of universal machinery, the prime cost of construction of each of the types listed was found to be approximately as follows:

Chair A. All wood, four legs $2.74
Chair B. Wood with steel bracing, four legs 2.90
Chair C. Wood bench type, four seats together, cast iron legs 2.52
Chair D. Pressed steel frame riveted, four legs, wood seat and tablet arm 2.68
Chair E. Bolted steel frame, cast iron single column base, wood seat and tablet arm 2.64

To obtain the above figures, time studies were taken on the various operations with conditions paralleling as nearly as possible those under which the new design was made. Also material costs were obtained from the present market prices. These costs run in very accurate proportion to the prices quoted by the various manufacturers on the finished product. They are found to be about 66 per cent of the sales price. Of course,

these figures are taken on the average of the different designs in each type of construction. This percentage is high and could naturally be reduced in all cases, including that of the new design, by more up-to-date manufacturing system and equipment than were available to the writer.

These prices are quoted to the buyer approximately as follows: Chair A, $4.20; B, $4.45; C, $3.60; D, $4.10; E, $4.15.

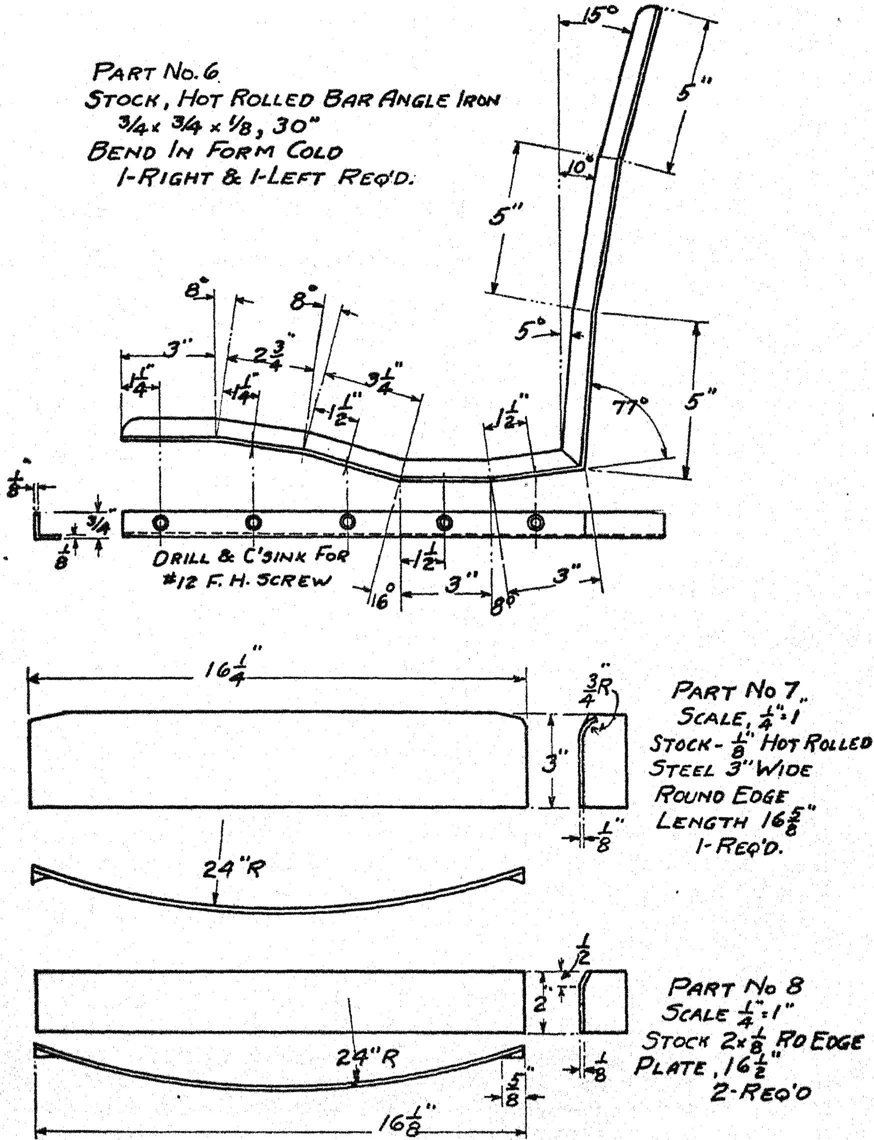

Fig. 5. Sides and back of seat frame, (part No. 6), are continuous and of bar-size angle. Back rests, (parts No. 7 and No. 8), are round-edge flat steel crimped and curved.

The new design could be quoted at \$4.15. The arc welded steel frame chair, then, falls in initial cost, about in line with other types on the market.

General Comparison.—From this point, the writer wishes to bring out the good and bad features of each type of chair, as seen by the students, instructors, business manager, and head of the repair department of the college, and show how the good features are accentuated and the bad eliminated in the new design.

A little more than 90 per cent of the classroom chairs in the college are fastened to the floor. This percentage runs even higher in most high schools. For this reason, consideration is here limited to that type of set up.

The majority of the chairs in the college is found to be of the type B, wood construction braced with steel. This chair is within a reasonable price range, attractive in appearance, fairly comfortable, meets utility requirements, and is enough more durable than the all wood chair to warrant the difference in price.

However, it is declared not satisfactory because of the following faults:

1. In a very short time it becomes loose-jointed and noisy. It is evidently not designed to be screwed to the floor. The steel bracing which consists of mere corner angles does not render the joints rigid enough to withstand the shock loads applied under daily use. After two or three years it becomes necessary to tighten or replace screws or otherwise strengthen joints. This must be done periodically to forestall necessity for expensive overhauling or entire replacement. In one department of the college, there are 327 chairs of this type. They were all tightened up less than a year ago. At the present writing, they are all racked and loose to the point that immediate attention is necessary to save them from going to pieces.

This trouble is taken care of in the new design by the fact that the frame is one solid piece of steel. There are no joints in position to work loose. Although the wood is held in place by screws, no load is put on the screws, and no wood is depended on in the least for the strength or rigidity of the unit.

2. In the wood chair the shelf for hat and books must be larger than necessary because, for facilitating construction, it must span the four legs. This affords a large area for collecting trash and dust, and is not easily accessible for cleaning. Another great objection to this shelf is that it aids the four legs in presenting a situation which all but defies the janitor's broom, vacuum cleaner, or mop.

In the new design the shelf is small, easily accessible, and well clear of the base. The base is thin edged and the column round, presenting no cracks or corners to catch dirt being swept over the floor. Resistance to broom or cleaning equipment is reduced to a minimum. A series of time studies has revealed that, aside from the fact that a much better floor cleaning job can be done around the column base chair, the time saved will reduce the janitor labor cost by a surprising percentage. This saving alone will pay about half the interest on investment on the chairs. These

figures were based on a janitor's wage of 20 cents per hour and assuming that the classrooms were swept three times a week, nine months a year.

Chair C is the wood bench type with four seats together. This design is low in initial cost, but has proved to be entirely unsatisfactory and is therefore being discarded and replaced by the single units.

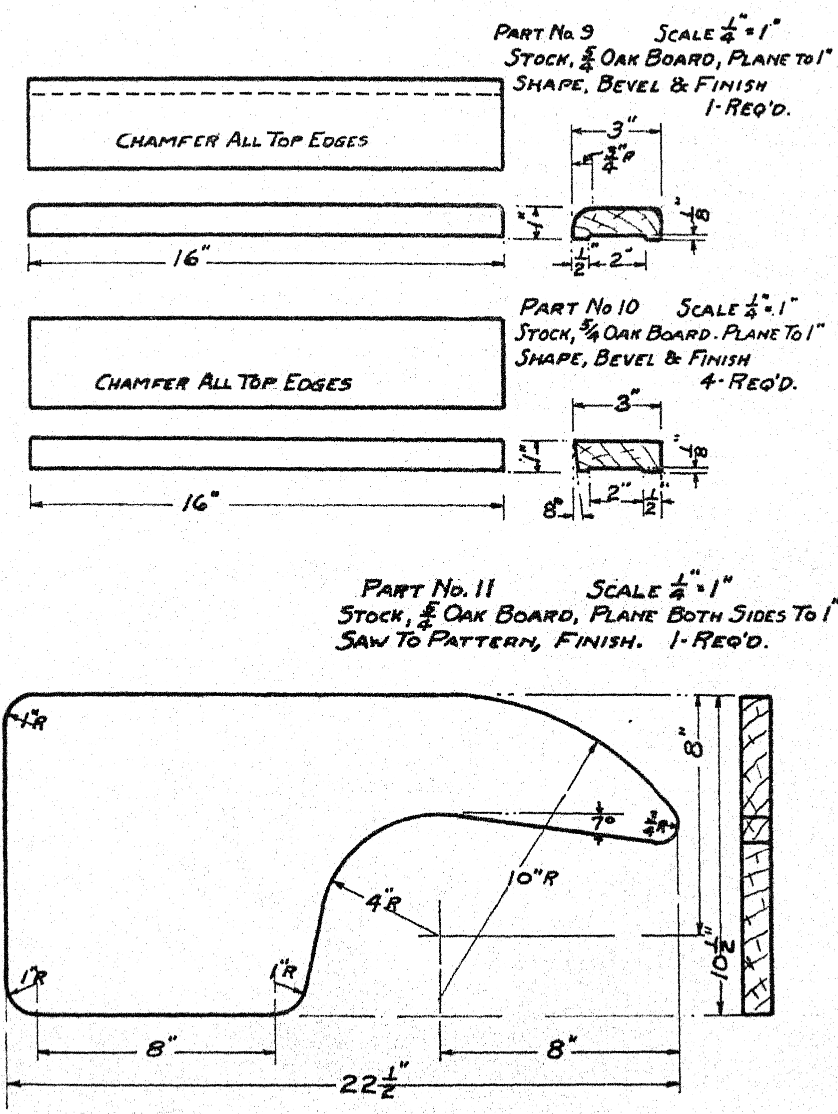

Fig. 6. Five pieces, (parts No. 9 and No. 10), comprise the seat. Tablet arm, (part No. 11), is one piece.

Chair D is of the riveted steel frame construction with wood seat and tablet arm. It is well proportioned and fairly comfortable. However, as in the wood chair, the book shelf and four legs, as well as the numerous dust-collecting parts, present a problem in cleaning. At every riveted joint, there are deep corners or open cracks to collect bugs or dirt. The frame requires about twice as many steel parts as does the arc welded frame. This is due largely to the necessity for using strap bracing for the riveted joints. To cut the material cost, these parts are made of light sections. Braces of long span are made of flat strips which bend easily, causing rivets in the thus-braced joints to work loose or even shear off. It was found that the use of this method of construction in a single column base chair, with all utility features, presented a difficult and expensive problem in closing up the column and bracing from it, around the book shelf, to the seat.

All of these faults and difficulties are taken care of in a very simple manner in the arc welded steel frame design.

Chair E is constructed with a single-column cast iron base, wood seat and tablet arm, wood or steel back rests, with framework of bolted or riveted steel. This chair, like the new design, is easy to keep clean, but is sadly lacking in comfort, utility, and durability. The seat is flat, as this type of construction does not adapt itself well to curved forms. It has no place for hat or books. The frame and base are bolted to the seat and depend on the thin wood for strength. The seat splits and the whole

Fig. 7. Simplicity of design characterizes the arc welded lecture room chair.

chair collapses. Attempt to improve these features with this method of construction brought out figures showing the cost to be prohibitive.

Of course these do not represent all of the types of lecture room chairs on the market. However, they do include all of the general types of construction within a reasonable price range of the chair described in this paper.

Summary.—The advantages of the arc welded steel frame chair over the conventional types is summarized as follows:

1. Attractive appearance: brought out by simplicity in design and by the use of a minimum number of parts.

2. Extreme durability: obtained by welding the complete frame, thus leaving no joints to work loose.

3. Comfort: emphasized by the curved and tilted seat which is voted by the students as better than the conventional saddle seat.

4. The small hat and book shelf: easily accessible for cleaning and too small to collect trash.

5. The thin edge base with single round column: presenting minimum resistance to floor cleaning.

6. Filleted corners and sealed lap joints: leaving no hiding place for bugs and dirt.

7. Sturdy members: having enough elasticity to absorb shock and impact to which the chair is continually subjected.

8. Perfect silence: obtainable by no other method of construction.

Besides these comparative features, there are others well worth noting. The seat is made in five pieces of simple shape, any one of which can be replaced at very little cost. In the case of the saddle seat, replacement means the whole seat which is an expensive piece of woodwork. The arc welded chair adapts itself well to special order changes in size and shape. More or less tilt in the seat can be obtained by lengthening or shortening one end of part No. 4, Fig. 4. The height can be changed by changing the length of only the one piece, part No. 2, Fig. 3. If the chair is to be used on a sloping floor, part No. 2 is merely cut at the proper angle to take care of the pitch.

Chapter II—Modern All Purpose Steel Table Designed for Arc Welding

By Paul J. Birkmeyer,
Engineer, Western Union Telegraph Co., New York, N. Y.

The table shown on the accompanying drawing, (See Fig. 1), is especially suitable for use in conference and directors' rooms. The table may also be used in public buildings such as hotel lobbies, libraries and other places where patrons and the public expect to find a better grade table. By increasing the height of the upright panels, the same construction and design may effectively be followed in providing tables for post offices, stations and other places to fulfill standing position table needs.

To fulfill the requirements of the many types of services listed above, the table must naturally be subject to many variations of top material, finish and color. The top material is recessed into the top and supported by heavy gauge flat steel plate. Any of the usual flat top materials as described under "Design and Construction" may be set into the recess flush with the steel border top plates. The steel borders are narrow in order to obtain the maximum benefits from the top material selected. The steel top border plates and the upright steel panels are subject to many variations in finish and color. If it should be desired for any special condition, metal decorations may be readily fastened to the upright panels with studs.

Design and Construction.—The design is modern in character and lines. The arc welded construction used throughout readily suggests a quality of permanence, which is too frequently lacking when "modern lines" is the primary requisite. The design as worked out herein lends itself to the effective use of sound structural members for strength and permanence. These same qualities of strength and permanence are carried through to the finished product as reflected in the general appearance of the table.

Functional utility was not overlooked. The rounded sides add to the comfort of the user. The top material may be varied to include bakelite and other plastics which may be obtained in acid proof and blister proof quality; or linoleum adapted to many variations in color and design; or glass with colored and fused designs or clear over pictures, posters, etc.; or steel finished and baked both smooth and wrinkled in all colors and readily etched to reproduce the skill of the artist. The small steel top border, as previously referred to, in no way counteracts the advantages of the top material chosen for any condition. The stainless steel base plate is provided to prevent tarnish from toe marks or from the mop.

Cost.—The cost of the table is not high when consideration is given to its size and the type of place for which it is intended. The table, as designed, could reasonably be constructed only by arc welding and it,

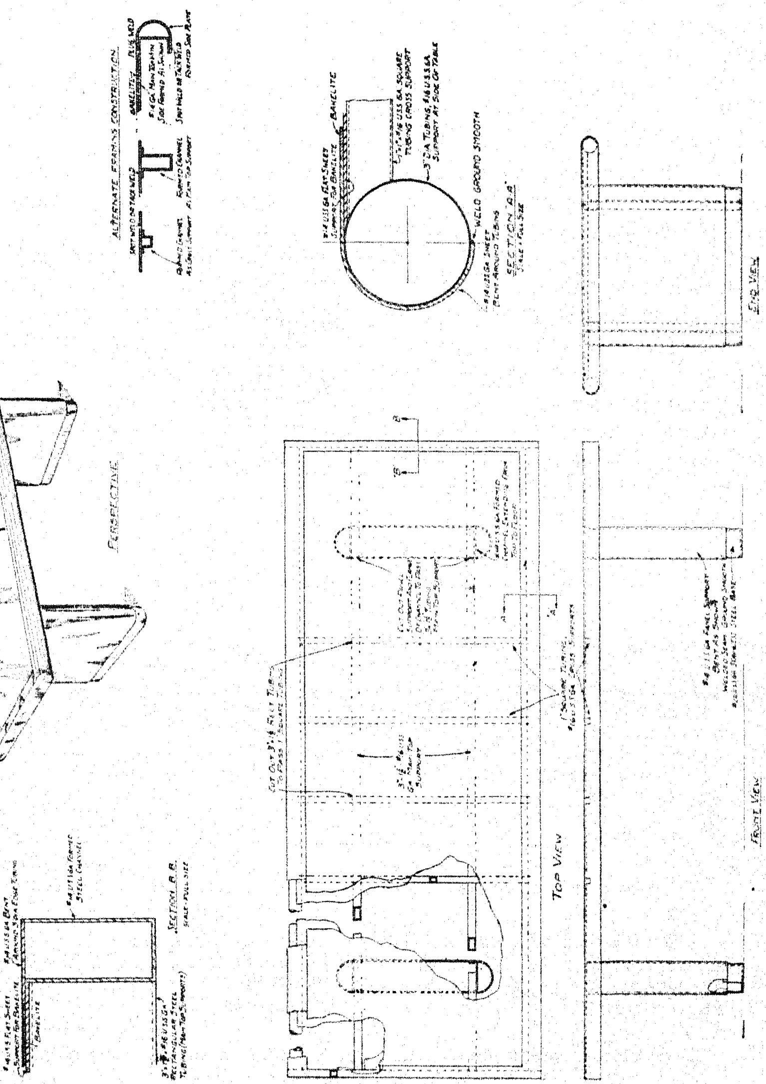

Fig. 1. Modern all-purpose arc welded steel table.

therefore, would be impracticable to prepare for comparison purposes, figures on other types of construction.

The total cost of $90 shown is based on the manufacture of a 10 x 4 table constructed as shown on the drawing. Black bakelite cost figures were used in arriving at the cost of the top. Standard linoleum patterns would be slightly less in cost. Colored bakelite would increase the cost approximately $6, while figured bakelite would be somewhat more expensive depending on the type. Furnished with a heat-treated glass top, the total cost of the table would be approximately $120.

The substitution of formed channels for the standard tubing would decrease the cost of material approximately $12, but would entail an additional labor charge for forming the channels. The relative merits of the two types of construction would depend on the quantity required, skill of the welder and the use of proper cooling plates. The standard steel tubing would be stronger and, if properly applied by tack welding or continuous arc welding with cooling plates to prevent warping, would probably be preferred when tables are ordered in small quantities.

All material costs used, were quotations by standard suppliers less the the usual discount to shops and smaller factories. Arc welding costs were taken from the "Procedure Handbook of Arc Welding Design and Practice," allowing 200% set-up time.

COST CHART

4 x 10 Table Constructed in Accordance with Drawing, Fig. 1.

Material

	A. Steel Sheets — No. 14 U.S.S. Ga.	
1	Main top supporting plate, 4′ x 10′, 125 lbs. @ .07/lb. (This includes material for 4′ x 2″ top surface plates at each end)	$ 8.75
2	Rolled side plates, 10′ x 6″, 15½ lb. each = 31 lbs. @ .07/lb.	2.17
2	End formed channels, 4′ x 7½″, 7½ lbs. each = 15 lbs. @ .07/lb.	1.05
2	Oblong panel upright supports, 5′–6″ x 2′–3″, 38½ lbs. each = 77 lbs. @ .07/lb.	5.39
4	Formed channels inside upright supports, 2′–6″ x 9″, 6 lbs. each = 24 lbs. @ .07/lb.	1.68
	Total cost of steel sheets	**$19.04**
	B. Standard Welded Steel Tubing — No. 16 U.S.S. Ga.	
2	Main supports, 3″ x 1½″, 10 ft. each = 20 ft. @ .30/ft.	$ 6.00
4	Cross supports, 1″ x 1″, 3′–9″ each = 15 ft. @ .18/ft.	2.70
2	Round side tubes, 3″ dia., 10 ft. each = 20 ft. @ .40/ft.	8.00
	Total cost of steel tubing	**$16.70**
	C. Stainless Steel Bases — No. 20 U.S.S. Ga.	
2	Stainless steel bases, including sides and bottom, 4 sq. ft. each = 8 sq. ft. @ 1.5 lb./sq. ft. = 12 lbs. @ .70/lb.	$ 8.40
	D. Bakelite, Black, 1/16″ Thick	
1	Bakelite Panel 9′–8″ x 3′–6″ = 34 sq. ft. @ .30/sq. ft.	10.20
	Total Cost of material items A, B, C and D	**$54.34**

Labor

A. Arc Welding Costs

2	3" x 1½" main supporting tubes to main top supporting plate	*20'
4	1" x 1" Cross support tubes to main top supporting plate	*15'
2	3" Dia. round side tubes to rolled side plates (2 welds)	40'
2	Rolled side plates at each side to main top supporting plate	20'
2	Top surface plates at each end to main top supporting plate	8'
2	End formed channels to main top supporting plate (2 welds)	16'
2	Oblong panel upright supports to main top supporting plate	11'
2	Oblong panel upright supports, ends of sheets welded together	5'
2	Stainless steel bases (2 welds — full perimeter of oblong panel upright support — one for bottom of base and one to steel panel)	22'
4	Formed channels inside upright supports (2 — 2'–6" welds each)	20'
	Total Feet of Arc Welding	177'

*Based on one continuous fillet weld one side of tube only — If tack welded, these figures would also be conservative in allowing for welding tube cutouts as well as cutouts in panel upright supports.

Referring to the "Procedure Handbook of Arc Welding Design and Practice," the curves on Page 402, 1936 Edition, fillet and lap welding, do not continue to include No. 14 Ga. plate. The figures for ⅛" plate, however, should be conservative. From these curves showing 45 ft. per hour at $2.00 per hour, the labor cost would be 4.4 cents per foot and the material would be .05 lbs. per ft. at $ .09 per lb., or $ .005 per ft. Labor and material would be $ .044 + .005 or $ .049 (say 5 cents per ft.).

Straight cost of welding 177 ft. @ $ .05/ft.	$ 8.85
Allowing 200% set-up time which should include grinding, forming rolled side plates, tube cutouts, etc., add	17.70
Total Steel Labor Cost	**$26.55**

B. Enamel and Baking Costs

Estimated cost to include material	$ 5.00

C. Installing Top and Incidentals

Estimated cost to fit the Bakelite top, and cement it in place, and other incidental labor costs	$ 4.11
Total Labor Costs—A, B and C	$35.66

Total Cost

Total Cost of Table including Material and Labor ($54.34 + $35.66) $90.00

Chapter III—More Advanced Design and More Rigid Construction of Chromium Tubular Furniture

By Clinton Bolin,
Draftsman, Lloyd Mfg. Co., Menominee, Mich.

In the fall of 1936, a nationally known furniture designer sent a number of new designs to the factory for the 1937 line of chromium tubular furniture. Among these was a suite composed of a chair and davenport, the main feature of which was the use of three streamlined ovals of tubing fastened tight together, forming the ends of the chair and davenport respectively.

The problem of plated tubes tight against one another had been avoided by the factory designers. It was considered impractical to manufacture due to need of polishing and plating with the tubes fastened together as one unit. Plating was almost impossible in the crevices where the tubes came together, and it was more costly to polish because an extra thin wheel had to be used to get down between the tubes.

If the pieces were polished and plated as separate units and then fastened together, rivets or self tapping screws would have to be used, which was against the designer's wishes. He demanded that the chair end be rigid and free from any projection of a rivet or screw head above the surface of the tubing. This was logical because this chair end acted also as the arm rest, and anything projecting above the surface of the tubes would catch in clothing or scratch a person's hands or arms.

It was decided then that the three ovals would have to be polished and plated as separate units and then fastened together. Here is where the problem started, because as previously stated, the design must be smooth and free from any projecting screw or rivet heads. Nevertheless, rivets and self-tapping screws were tried and the heads were countersunk in the tubes to keep them from projecting above the tube surface. This method of fastening, however, did not make a rigid enough job because rivets tend to bend inside the tube as soon as the riveting starts, thus preventing a tight fastening. Nor did self-tapping screws make a tight enough fastening nor smooth enough job.

When chromium plated tubes are touching each other, they must be held absolutely rigid, because a very slight movement produces a very annoying squeak which had to be overcome. The only method of fastening seemed to be welding, but objections were raised that the plating around the weld would be spoiled. This was true of the type of welding with which we had experience. The intense heat and the fact that it travels very fast along an 18-gauge steel tube, caused the plating to be spoiled. Everyone seemed to be thinking in terms of the former type of welding because approximately all welding in the chromium tubular furniture industry is done by this method.

At this point I suggested that the tubes should be arc welded together at points in the crevices on the underside of the tubes. I thought the

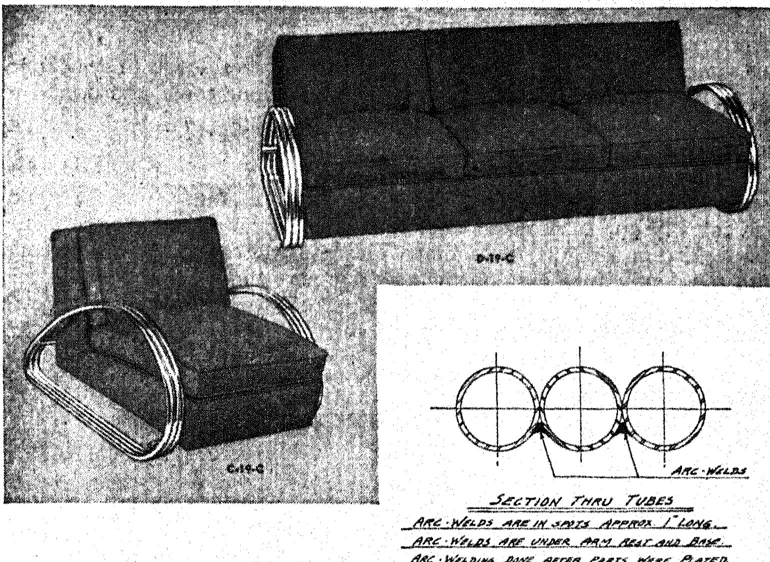

Fig. 1 Plated tubes arc welded together made this furniture possible.

plating would be all right around the weld, because the big feature of arc welding is the low heat outside of the actual welding area, thus protecting the plating around the weld.

After some discussion, it was decided to try arc welding, so a few pieces of plated tubing were secured and experiments begun. After some experimenting, it was found that by using 60 amperes and a $\frac{3}{32}''$ diameter electrode, that a very excellent weld was made, free from spattering, and the plating around the weld was as good as ever.

A chair was then made up and arc welded after all parts had been plated. The welding was done in beads approximately an inch long in the underside crevices where the tubes came together. The welds were then painted with a coat of aluminum paint to keep the weld from rusting. Each chair end was very rigid and the welds were completely hidden from ordinary view.

The upholstered part of the chair, that is the seat and back, were suspended on two tubes which in turn were fastened to the chair ends. These tubes were fastened to the chair ends with a small arc weld and self-tapping screws. The self-tapping screws were used here together with a small weld because of the extreme load at the fastening point, and a large weld would be too noticeable. The self-tapping screws were not objected to because they were out of the way and could not catch on anything.

The chair was completed and proved a very solid unit, as modern and streamlined a piece of furniture as was ever placed on the market the second week in January 1937. (See Fig. 1). It was acclaimed by everyone who viewed it as the most modern and streamlined suite of furniture at the show. Thus, arc welding made possible this advanced design.

This suite however, was made for the higher priced bracket, and therefore was out of the reach of the general public, so in the 1938 line this same designer presented the same feature of this design in a medium priced bracket, (See Fig. 2), which almost everyone could afford, and it sold for the same price as was formerly charged for furniture of plainer and more conventional design.

To bring out this feature in the 1938 line, the two-tube idea was used. On one particular chair and davenport, the double-tube chair end was actually one tube, made so after all the necessary bends were made and welded in a regular butt joint. This end was then like a single coil, with the double tube only on the arm rest part and a single tube on the base. This meant that the double-tube portion would have to be spread apart while plating and polishing and then be arc welded together.

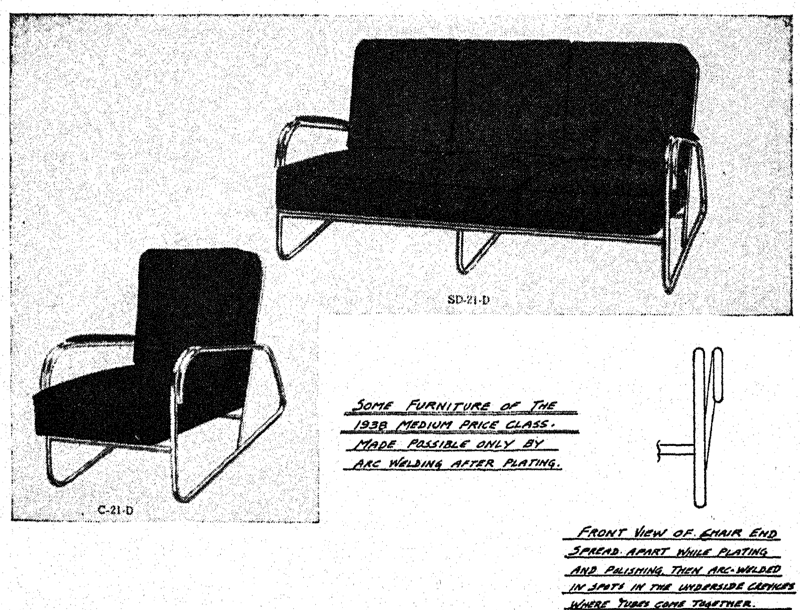

Fig. 2. Ability to arc weld after plating produced this medium priced furniture.

During 1937 the plating department, not to be outdone, had conducted some experiments on plating tubes which were tight together. They said they could do the plating job on this double-tube chair after the tubes had been welded together. This would give a better job because the other method of springing the tubes apart while polishing and plating, would pull the chair ends out of shape. There would not be any noticeable extra cost in polishing because the two tubes were only on the arm rest which was only a short section.

It was then decided to try to polish and plate the chair end after the two arm tubes had been brazed together in spots in the underside crevices where the tubes came together.

In polishing, a very thin wheel was used to get down between the tubes as far as possible. This was accomplished fairly well and without too much bother or waste of time from ordinary polishing procedure. Plating was tried and a fair job resulted. Plating occurred all over except an area about a fourth of an inch wide all along the center portiòn where the tubes touched together. This portion was plated, but very thin, and when nickel buffed, if the buffer wasn't extremely careful he would easily cut through the plating. In general appearance it was satisfactory, but we knew that within a short time the real effect of this thin-plated portion would tend to spoil the entire job, because it would tend to corrode and peel. This method of doing the job would prove too costly because in production polishing and plating all pieces are not given such careful attention as was given this chair in the experiment. If everything was not just right, "shading" and rough plating would result. The pieces would then have to be stripped and repolished and plated, thus not only adding to the cost, but actually holding back production which is even more costly.

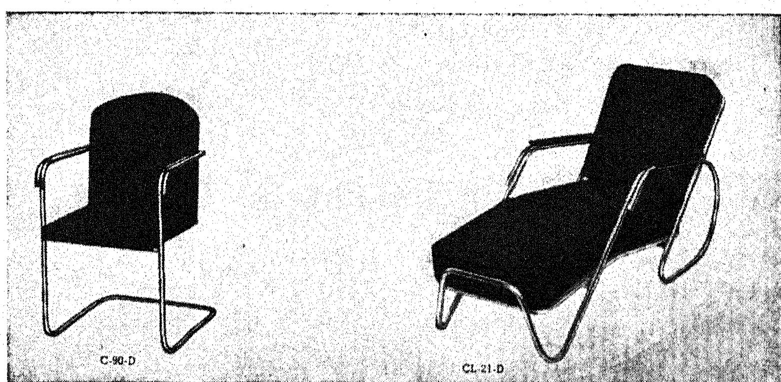

Fig. 3. Arc welded two-tube furniture.

After this experiment, a chair was polished and plated with the tubes spread apart and then arc welded together and a perfect job was accomplished.

The other chairs in the line that had the two-tube feature were made in separate pieces and arc welded together after they were plated. This gave the chairs and davenports the sturdy construction as only welding can give, and smooth design free from unsightly rivets or screws. Its general acceptance at the 1938 furniture show was real evidence of its outstanding value and design. (See Fig. 3).

Thus, it can be said, that the only way the designer's ideas could be carried out was by arc welding after plating. Any method other than arc welding would have been too costly and in the final analysis would have resulted in an inferior product. In other words, arc welding proved to be the only right way to do the job.

The service life of the furniture is greatly increased because of its rigid construction and there is real economy in the long life. The consumer received a better product of advanced design, at no increase in price over more conventional but less rigid design.

This method of arc welding after plating can be used throughout the chromium furniture industry, in eliminating rivets and screws in places where the weld is not noticeable, and giving more rigid and smooth design. It will broaden the field for the designers, who heretofore have been limited because of plating, polishing, and assembly problems.

Chapter IV—Desk and Seat Frames Fabricated by Arc Welding

By E. Christie,
Welding instructor, Army Vocational Training Centre, Thornhill, Aldershot, Hants, England.

The accompanying photograph, Fig. 1, illustrates a type of desk and seat frame extensively used in schools and lecture halls.

Hitherto, these frames have been made by casting, and after one or two years use, one can generally observe a fair percentage of fractures to these frames. Further the weight is considerably more than is necessary. This is a definite disadvantage when floor space is required and these cumbersome articles have to be transferred to another position. The weight of each frame is 60 lbs.

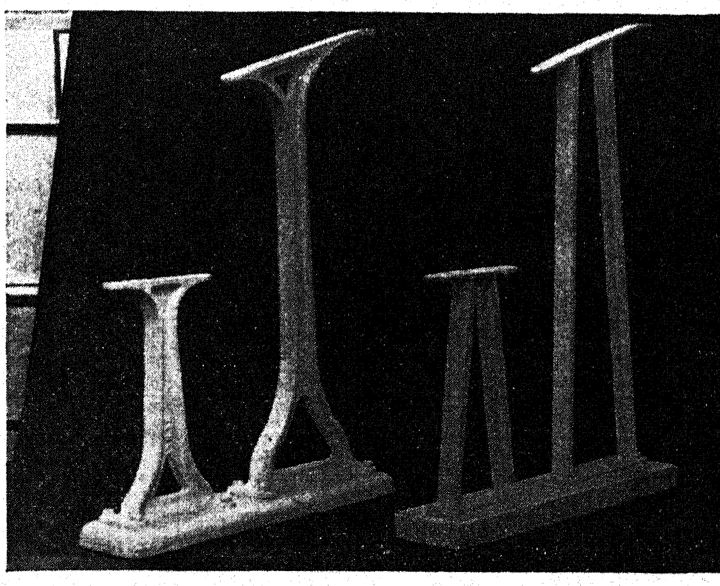

Fig. 1. Desk and seat frames. Left: cast iron, weight 60 lbs., cost $3.03; right: arc welded, weight 28½ lbs., cost $1.82.

In endeavoring to produce an article fabricated by welding to supersede these castings, I was principally concerned with weight reduction. This, I consider, has been satisfactorily achieved, as the weight of the welded frame is 28½ lbs.

A simple design has been adapted which facilitates easy fabrication. It is quite a simple matter to assemble the parts in a jig, weld and re-

move complete in 30 minutes. No cleaning is required and the frames are ready for painting immediately they leave the jig.

When finally completed, with desk tops and seats, the frames present a neat structure easy to handle, yet strong enough to withstand the most tempestuous treatment without fracture.

In addition to the advantage of weight, there is also a considerable saving in cost. This is based on the assumption that castings of this type can be produced at a cost of 2½d per lb. Therefore, the cost of each frame made in cast iron is 12/6d, ($3.03).

The cost of a fabricated frame is arrived at by the current prices for rolled iron sections, flat, tee and channel, 21/6d, ($5.22), per cwt. Labour cost, for cutting lengths, drilling holes and welding, at 1/6d, ($0.36), per hour, to which is added electrode costs and current consumption, is as follows:

28½ lbs. rolled iron section at 21/6d per cwt.	5s	6d	= $1.34
¼ hour cutting lengths at 1/6d per hour		4½d	= .09
¼ hour drilling 9 holes at 1/6d per hour		4½d	= .09
½ hour welding at 1/6d per hour		9d	= .18
Electrodes, current, etc.		6d	= .12
Total Cost	7s	6d	= 1.82

It should be pointed out that if the buying of rolled section was in bulk orders, the cost of the material would be reduced still further with a greater saving in the cost of the fabricated frames. Leaving out the fact that the welded article has a neater appearance and that the possibility of fracture has been almost eliminated, the two principle factors, cost and weight are definitely in favour of the fabricated article.

Frame	Weight	Cost
Cast Iron	60 lbs.	12/6d = $3.03
Fabricated	28½ lbs.	7/6d = $1.82
Savings by Arc Welding	31½ lbs.	5/- = $1.21
% Savings by Arc Welding	52½%	39%

Chapter V—Application of Arc Welding to Manufacture of Sheet Steel Bath Tub

By F. E. STEELE,
Designing engineer, Shreveport, La.

Many changes have been made both in material and design since the appearance of the first bath tub in ancient times. Materials have ranged from the precious metals and porcelain to cast iron. In recent years, the trend has been toward a substantial and low-priced tub that could be made available for the most modest residence.

Statistics published by the American Society of Sanitary Engineers reveal that considerably less than 20% of the homes in the United States are equipped with bath tubs indicating that a vast potential market exists for an economically-built bath tub.

At the time work was begun on the subsequently described process of manufacture, an investigation was made of the European market for such equipment and it was found that to reach this market a unit would have to be built that was light in weight and could be easily packed for foreign shipment. The subject design is particularly adaptable to crating in that it is light in weight and one tub can be "nested" within another, thus reducing shipping space.

Process of Manufacture.—Reference is made at this time to the accompanying drawing, Fig. 1, illustrating schematically the process of manufacture. A 48″ x 60″ sheet (AAAA) of No. 12 gage sheet steel is placed into a specially designed punch press and in the first operation the rounded top section (ABBA) is pressed and sheared at line (BB). The rounded section sheared in the first operation drops into a die in the same press and is formed into the bottom of the tub noted as (CC). A second rectangular sheet of No. 12 gage steel (24″ x 60″) is placed into a specially designed press cutting and forming the two sides of the tub (DDEE). The four parts are then assembled on a magnetic block and arc welded together, necessitating two horizontal welds and vertical welds on each end. Openings are then cut for the drain, overflow and water connections. Legs are shaped from the middle section (DDDD) and arc welded to the bottom of the tub. Next the unit is passed through a pickling bath to relieve strains and thence into the enameling furnace from which it is ready for crating.

The above described process can be applied to either a built-in fixture as shown in Fig. 1 or to the open-leg-supported fixture.

Cost Analysis

Built-in type of tub.

Sheet steel No. 12 gage—30 sq. ft.—124 lbs. @ $2.70	$ 3.35
Welding—24 lineal feet	2.20

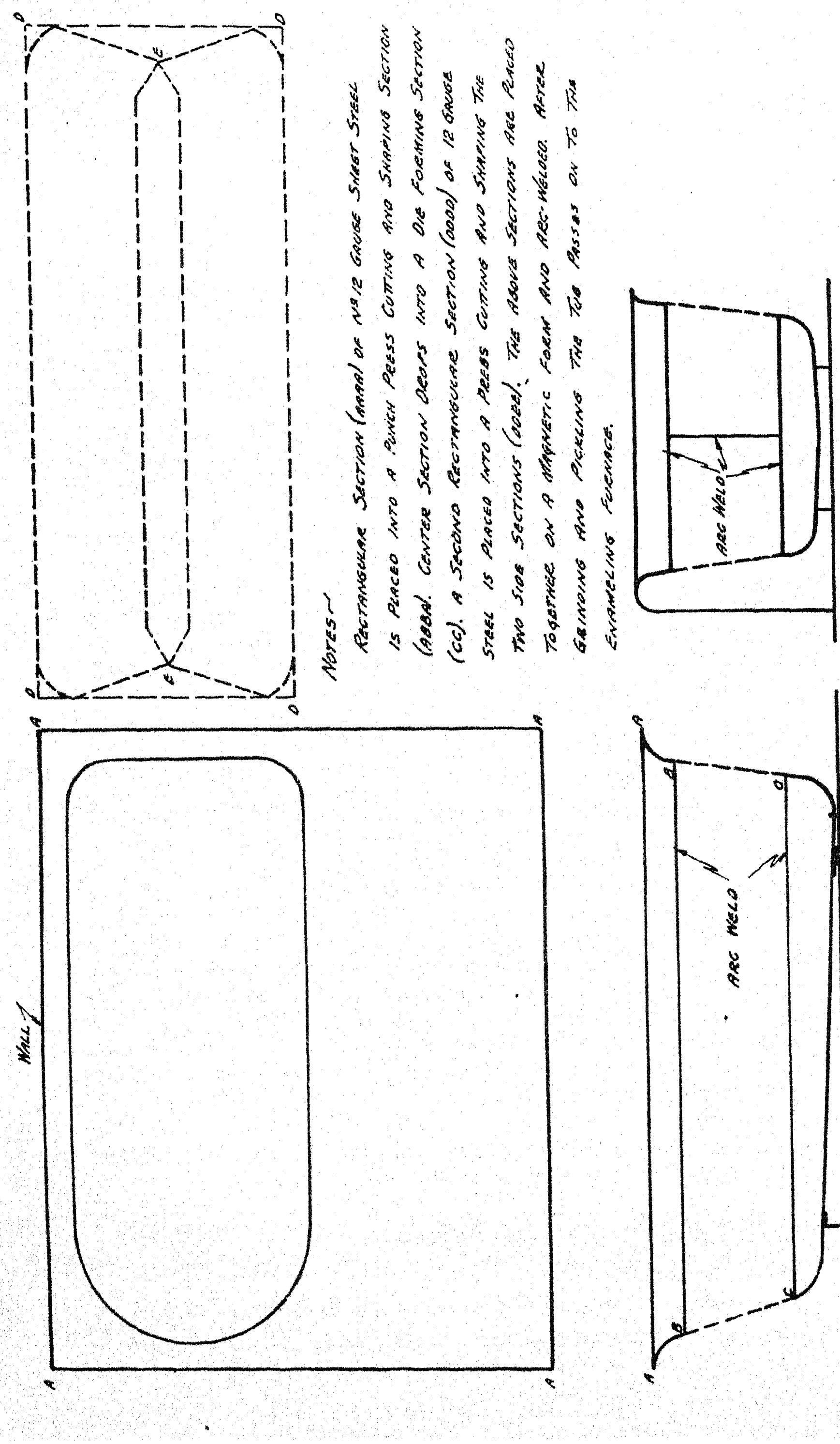

Fig. 1. Schematic drawing of arc welded steel bath tub.

Enameling	2.50
Miscellaneous	2.00
Total	$10.05

Comparison of Costs

Arc-welded enameled steel tub.		Enameled cast iron tub.	
Size	5′–0″	Size	5′–0″
Manufacturing Cost	$10.05	Manufacturing Cost	$23.70
Shipping Weight	155 lbs.	Shipping Weight	450 lbs.
Freight Rate/1000 miles	$ 1.66	Freight Rate/1000 miles	$ 4.81
Total	$11.71	Total	$28.51
			11.71

Savings by arc welding	$17.80
% Savings by arc welding	62.3%
Saving in manufacturing and shipping cost per tub at point 1000 miles from point of manufacture	$16.80

Conclusion.—The general adoption of the above-described arc welding process would result in more than 60 per cent reduction in the manufacturing cost of bath tubs which in turn would create a much larger market and, in the final analysis, tend toward a greater degree of sanitation in the lower-priced homes throughout the country.

Chapter VI—Lighting Fixture in Iron and Arc Welding

By Harold C. Whitehouse,
Architect, Spokane, Wash.

This is a day of great progress in science. We have at hand machines of many kinds to save labor costs in all kinds of industry. Surely, one of the outstanding machine methods is the arc welding process.

In presenting this paper, I wish, before going into the details of the subject, to bring out a few points that made the actual execution of this piece of work an interesting experience.

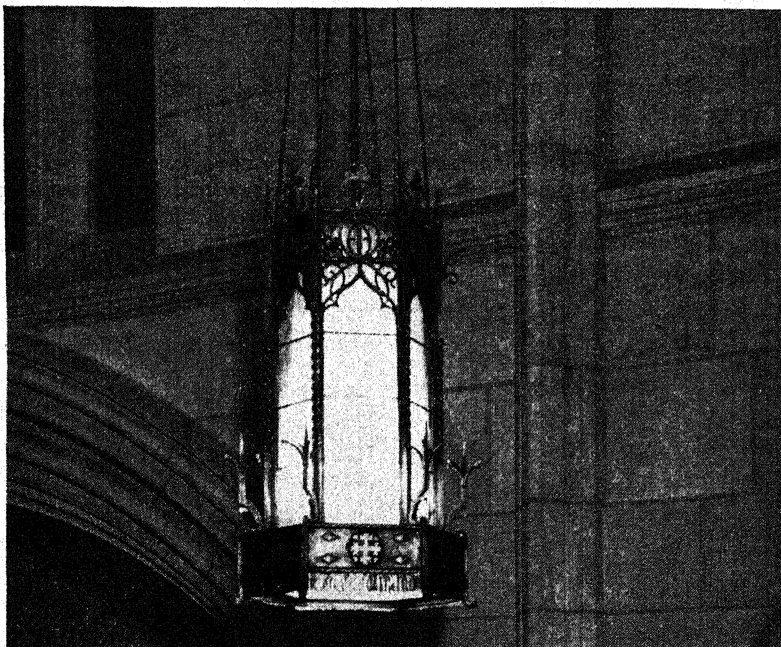

Fig. 1. Lighting fixture fabricated by arc welding for $210, compared with $250 by old-time method.

We in the field of architectural design are trained to draw from the "quarry of antiquity" much inspiration for our work. We study the general design and spirit of the technique that the early master crafts- men used with the limited materials and methods they had at hand. No other course for them was possible, but, today, we are in an entirely new age, alive with opportunities. However, there are those who do not like to "let go" of the old methods and techniques; they still want to design and execute works in the old manner. This spirit should not be con-

demned. Nevertheless, because mounting labor costs make prohibitive the execution of such works designed in the old manner, we are obliged to turn to up-to-date methods.

It was my task to design a lighting fixture, (See Fig. 1), to fit a certain condition, somewhat in the spirit of the old craftsmen, but we pick it up and carry on where they had to leave off. Our crafts can be so designed as to be in the spirit of the old work, modified to fit the economical and quick processes we have at hand. At the same time we can produce creditable works of art and craftsmanship that will equal the works that have been done before us.

In executing this project it was interesting and gratifying to obtain the result desired because of the economy in the use of the arc welding process. The design was originally made to breathe, in part, at least, the spirit of the mediaeval craftsmen. The objective was to imitate the old method of welding and the hammering out of the various members of Gothic tracery patterns into varying widths and thicknesses in order to obtain a spirit of technique that more or less emulated the early mediaeval craft work. I found, however, that this was making the fixtures cost \$250.00 each because of the great amount of labor involved. This amount did not include the electrical fittings, glass panels, etc., and as this was beyond the budget allowed, I set to work and redesigned the fixture. It was in this redesigning I discovered and learned more of the methods of arc welding. I acquainted myself more thoroughly with the process by visiting the shop of the craftsman, and I evolved a design that cut the cost of each fixture \$40.00.

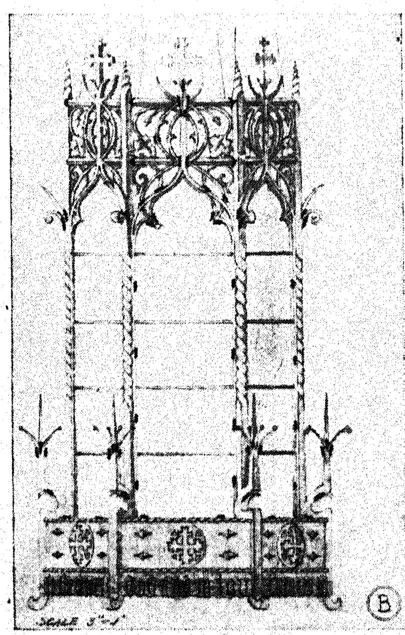

Fig. 2. Sketch of lighting fixture showing welds in fabrication. Scale = 3" = 1'.

The main change in the design was the use of simple rectangular sections, "oblongs" and "squares," which in most cases were bent cold, to fit the full size details of the design. These were cut and simply butted together and arc welded. The arc welded joints were filed slightly afterward, leaving only a small amount of the welding to increase the effect of the joint. This gave a desirable effect and took away the otherwise stiff mechanical joint, helping in the easy flow of the lines of the tracery.

The accompanying drawing, Fig. 2, shows, by means of black dots, the places where arc welding was used.

The vertical twist members were square bars placed in the fire and twisted to the desired effect.

The leaf motif was hand-hammered from the plain iron and welded as shown.

To design and supervise the execution of these fixtures was an education. I had on many occasions used arc welding in my work but never had become so well acquainted with the process heretofore. With this simple experience, I feel that I have lost many opportunities in the past to gain desired effects through economy of arc welding in much of my wrought iron work, such as in gates, grilles, light fixtures, furniture, doors, balconies, stairways, etc. I shall design much work in a new spirit hereafter by keeping in mind the arc welding process, in other words, design my work to fit the process. I feel now that this is a scientific method that can go hand in hand with decorative iron work. What an opportunity!

Chapter VII—Application of Electric Arc Welding to a Pair of Wrought Iron Candlesticks

By Henry P. Print,
Senior partner, Print Bros., Eynsham, Oxon, England.

Although contrary to the old principles of ornamental ironwork, a customer was persuaded to let us apply welding to a pair of wrought iron candlesticks, the condition being that no trace of weld at any point was to be seen upon close inspection.

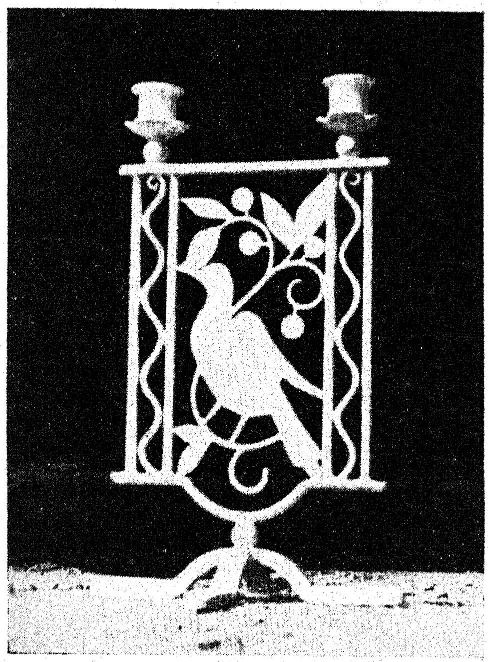

Fig. 1. Arc welded candlestick.

The candlesticks, (See Fig. 1), were originally designed for fire welding and riveting—the traditional method—but in redesigning no big alterations were necessary. The drawing, Fig. 2, is a copy of the original and shows welds numbered in order of execution. The photograph, Fig. 1, is the finished electrically welded candlestick.

It was decided to make one unit using arc welding and another by another method of welding, the same preparation being used in each case.

First, the four feet were forged separately true to shape from $3/4'' \times 3/8''$ mild steel, two being left a $1/4''$ shorter to butt on the sides.

These were then "vee" ground, butted and welded, (weld No. 1), then cleaned.

By the old method, it would have meant 3 fire welds then forging to shape, a far more difficult task than if done separately. Roughly, this would have taken four times as long as the new method.

The ball was next forged, being a simple sphere having no squared lugs for riveting, saving considerable time. The ball was then welded (weld No. 2) to the top of legs. Next, the bottom and top members of the frame were made from ½" x ¼" half-round mild steel, the bottom arched, one being welded (weld No. 3) to the top of the ball. The four straight uprights were cut off ¼" round then clamped into place and welded (welds Nos. 4 to 11). This saved the turning down of ends and all drilling. The two top balls were then forged, the saucers cut from

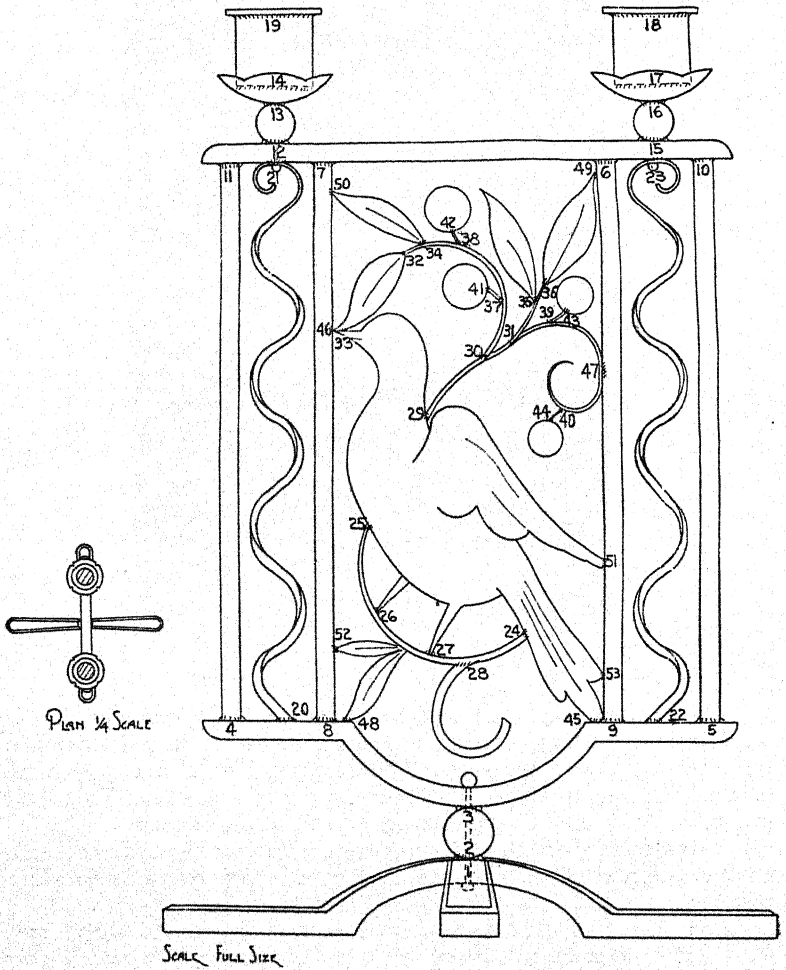

Fig. 2. Sketch of candlestick. Numbers indicate location and sequence of welds.

$\frac{1}{8}''$ plate and dished, the holders being two $1''$ pieces of $\frac{7}{8}''$ tube. The three separate pieces were then clamped into position and welded (welds Nos. 12 to 17). The holder flanges were $\frac{7}{8}''$ washers cleaned round and welded on (welds Nos. 18 and 19). By the old method, it would have been necessary to forge the balls with square lugs for riveting and the holders would have had to have been flanged in at the bottom and cut at the top, the saucers and top frame member drilled and squared to be riveted at the same time fixing the scroll-curled relief.

At this stage, all welds were cleaned up with rotary files and by hand. It was found that only in two places was it necessary to deposit a little more metal.

The time for the other method of welding was approximately half as long again as for arc welding, also causing considerable distortion which necessitated a fair amount of straightening.

The scroll-relief panels were made from two $9''$ pieces of $\frac{1}{4}'' \times \frac{1}{8}''$ mild steel, placed in position and welded (welds Nos. 20 to 23.) Distortion was again considerable by the other welding method. By the old method of fire welding and riveting, a lug for riveting would have had to be left at the bottom and the top would have had to be drilled.

The dove and olives were cut from $\frac{1}{8}''$ plate, the leaves from $\frac{1}{16}''$ plate, and the main stems from $\frac{1}{8}''$ round mild steel in four separate pieces. One leaf stem and the four olive stems were $\frac{1}{16}''$ round.

The whole assembly was clamped down in place and welded (welds Nos. 24 to 44). All welds were then cleaned ready for fixing to frame. By the old method, it would have been necessary to cut the whole dove and branch complete in one piece from $\frac{1}{8}''$ plate, making a great deal of cleaning up to be done. Moreover, lugs would have had to have been left for fixing to frame. Finally, the whole centre piece was clamped into the frame and welded (welds Nos. 45 to 53) and cleaned.

The whole was then rustproofed and painted. The total saving in time by arc welding over the other method of welding was 45% due mostly to freedom from distortion. Over the old method of fire welding and riveting, not tried but estimated, the saving by arc welding was 300%.

SECTION VII

COMMERCIAL WELDING . . . AUTOMOTIVE REPAIR . . . WELDERIES

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SECTION VII

COMMERCIAL WELDING . . . AUTOMOTIVE REPAIR . . . WELDERIES

Chapter I—Organizing and Operating a Job Welding Shop on a Business-Like Basis

By HOWARD McCORD and FRED H. DREWES,
Foreman, welding department, W. G. Jarrell Machine Co., and consultant, Charlotte, N. C., respectively. Complete paper contained 18,000 words and 15 illustrations.

Preface.—In the opinion of the writers of this article, there is a glaring need for information which will enable the Commercial Welder or Job Shop to properly organize and operate a business on a business basis. Such information is needed by the owner of even a fair business to enable him to organize his business for further expansion.

It is with this thought and our sincere belief in the interest of the development of Commercial Welders or Job Shops in which we are vitally concerned and connected with, that has prompted us to write this article and we feel that its publication in whole or in part will prove of great interest and of lasting benefit to thousands of commercial welders and job shops throughout the land.

Reputation.—Whether you buy a house, an automobile or have a broken machine or part welded, you must depend largely upon the reputation of the concern from whom you buy or whose services you procure. The highest salaried buyers in the world agree that they would rather buy goods produced by a concern with a good reputation, without inspection, than to trust to their own judgment of goods produced by a concern without an established reputation.

Modernized Weldery.—Unless your material handling facilities adequately serve your weldery you cannot hope to realize substantial profits from your welding activities. Material handling methods of 1920 cannot compete in the 1938 market.

Equipment Needed.—Shop facilities must, obviously, be provided if an acceptable and profitable job welding shop is to be presented. Quite naturally any plan such as the one shown in Fig. 1 is of a tentative nature and must be adapted to existing buildings and facilities. The extent and arrangement shown represents an average layout consistent with budget limitations. It is perfectly feasible to install only one piece of equipment in each of the departments listed and still have a well balanced shop.

The following list of equipment is broken down for detail consideration and it should be emphasized here that although this layout represents a hypothetical laboratory or shop, the general arrangement and organization is the result of actual experience in planning and using

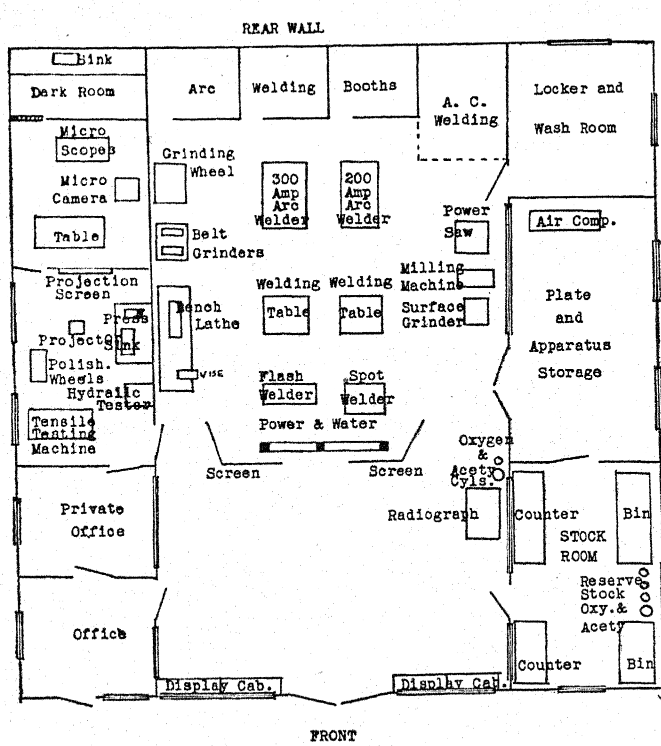


Fig. 1. Arrangement of commercial welding shop.

this layout. For this reason due consideration should be given major departures from the arrangement shown. Following is a detailed list of the equipment shown in the plan.

LIST OF EQUIPMENT

METALLOGRAPHIC: Micro camera, microscopes, polishing wheels, belt grinders, grinding wheels, dark room equipment.

X-RAY EQUIPMENT: Low-voltage machine, (capable of penetrating 1-inch plate).

PHYSICAL TESTING: Portable tensile & bend testing machine, hydraulic tester.

ARC WELDING EQUIPMENT: Single operator m.g. set 200-amp., one arc gasoline engine-driven trailer model 300-amp., a.c. transformer, 2 welding tables, 2 welding booths, 2 screens or shields.

RESISTANCE WELDING EQUIPMENT: Automatic flash welder, 35 kva. spot welder.

MACHINE TOOL EQUIPMENT: Power hacksaw, milling machine, surface grinder, bench lathe.

OXY-ACETYLENE EQUIPMENT: Hand-cutting torch, auto. st. line cutting mach. equipped for flame hardening, oxygen cylinder, acetylene cylinder or acetylene generator, rod storage racks.

MISCELLANEOUS EQUIPMENT: Air compressor, plate storage racks, specimen cabinets and display boards, hand tools, quenching tanks, lantern slide

projector, projection screen, work bench equipped with vise and built-in cupboard.

ACCESSORIES: Electrode holders, wire brushes, fibre helmet, fibre hand shield, welding gauntlets—leather and asbestos, welding goggles, 2 50-ft. lengths of hose or 1 50-ft. length of twin hose.

POWER SUPPLY: 110-volt a.c. (single phase), 220-volt a.c. (three phase), 110-220 volt d.c.

When a shop starts to expand, it is some time before there is a full realization on the part of the management that the shop has grown beyond the old shop layout. A good deal of cost and confusion will be eliminated through prompt reorganization and perfected layouts.

It should be borne in mind that additional facilities should be added to facilitate operating on a mass or production basis, for example, a complete designing or drafting room should be available that would be able to design the product in a preliminary way before the job is accepted, and to make the detail drawings before the job is sent to the shop.

The following plate has been found suitable to carry in stock (on the basis of the most suitable thicknesses):—¼-in., ½-in., ¾-in., 1-in., 1¼-in., 1½-in., 1¾-in., 2-in., 2¼-in., 2½-in., 2¾-in., 3-in., 3½-in., 4-in., 4½-in., 5-in., 5½-in., 6-in., 6½-in. and 8½-in.

It is also necessary to carry the following sizes of round bars:—½-in. dia., ¾-in., 1-in., 1¼-in., 1½-in., 1¾-in., 2-in., 2½-in., 3-in., 3½-in., 4-in., 6-in., 9-in., 12-in., 14-in., and 16-in.

The stock should also include standard size channels, I-beams and angles, and the necessary stock of different size welding rods and electrodes.

Hiring, Training and Managing the Men.—In hiring an arc welder it is essential that the applicant have knowledge of the fundamentals of arc welding. The applicant should have a knowledge of electrical terms and of the practical units used in electrical calculations. He should have knowledge of the installation, adjustment and operation of the welding equipment in use in the particular commercial welder or job shop to which he has applied for a position.

An applicant for the position of an experienced arc welder should be able to give the proprietor or foreman of the job welding shop a few practical samples or demonstration of his ability and knowledge. He may qualify by his actual operation of the electric arc welding equipment and his ability to use both the coated and the uncoated electrode according to correct welding procedure.

The welder's day should begin promptly at an appointed hour and if no special job or duty can be assigned during the first hour, he should be given an opportunity to progress in his work through practice and application on all machine equipment in the shop.

Each job should be carefully checked and the data tabulated and compiled and made available for consultation at a given hour each week for the purpose of noting the progress of the employee as to actual welding speed and pounds of electrodes used per foot of weld. Discussions at a weekly meeting, with employer and employee alike offering suggestions, should arise from such a meeting and a clearer

understanding of each other's problems in relationship to good management, as well as profit and loss in business, should result.

It is recommended that the student welder be put in the charge of the welding foreman until he can make a fair weld. His work at first should be confined to training on the scrap pile, then on light welding, then on short lengths of fabricated pipe, and finally all classes of welding either in the shop or in the field.

Advertising the Welder.—There are several methods of advertising open to the commercial welder or job shop and for purposes of clarity the writers of this article have arranged material in this section under the heading of "Indirect Advertising" and "Direct Advertising."

Under "Indirect Advertising" may be classified newspaper publicity and advertising, road signs and billboard advertising, printing of cards, window displays, advertising in trade papers and local publications, bus and street car advertising, the distribution of novelties as souvenirs and the advertising to be gained through the appearance of the shop and buildings.

Under "Direct Advertising" may be listed the following: personal contact by the commercial welder or his representative, direct-by-mail circular letter campaigns, listings in the classified business telephone directories and advertising through the medium of the motion picture.

Value of the Appearance of Shop and Office in Advertising.—Of all the forms of indirect advertising there is none as appealing and gainsworthy as the neat appearance of the commercial welder's shop and buildings. Whitewash and paint should never be used sparingly on the walls and ceiling in the shop and an orderly arranged office and storeroom proves inviting to a customer or prospective customer.

Advertising Gained Through Personal Contact.—Without question, the finest form of advertising is direct contact with a customer or prospect made by the welder or his representative and this fact should be everlastingly borne in mind by the commercial welder. The personality of the welder, his first thought of serving his customer and his straightforward, businesslike methods will prove his best advertising medium. Next to that comes the advertising to be gained by every properly consummated transaction with the customer or prospect. Living up to his word with respect to getting out the job on scheduled time at the price agreed upon with good workmanship forms a properly consummated transaction and is the best means of advertising.

When all is said and done the welder must experiment and check up on advertising to reduce his advertising costs to a low figure and at the same time, to increase his results by using definite advertising plans.

Process Promotions.—The most promising processes in customers' plants should prove the best available method of increasing the business of a commercial welding or job shop. In contacting customers the questions to be kept uppermost in mind are: (1) What classes of business are available in the immediate vicinity within easy reach?

(2) Which customers or prospective customers are good prospects for process promotion? (3) Is the job shop equipped to sell the processes to customers? (4) What processes are there to promote? (5) What further equipment is necessary to better qualify the shop to sell the processes to customers?

Below is a list of some typical commercial welder or job shop customers and operations by industries to encourage and stimulate the management of the commercial welder or job shop to apply the process of arc welding, from which more work and greater profits will result:

1. ADVERTISING CONCERNS—Fabricate, install, alter, repair welded framework for signs.
2. BAKERIES—Repair baskets (wire), conveyor rings, cake mixer machines, dough beaters, dough mixers, ice cream cone machine guide fingers, mixing bowls (copper or monel), pans, racks, slicing machine, storage tanks, and wrapping machine.
3. BRICK YARDS—Hardface auger machine, clay cutters, clay feeder shoes, dipper teeth, jarring bars, mixer blades, mud screw, pug mill knives, pulverisers, roll mill crusher plates, thrust collars, trip dogs.
4. COAL DEALERS—Fabricate and repair bins, boxes and containers, chutes and chute bends, conveyor bucket lips, heater tube pipes, hardface hopper lips, loaders, scale parts—pivots.
5. CONTRACTORS—Fabricate and repair anchor buoys from old dredge pipe, hardface cable drills, caisson digger cutter heads, crusher jaws, dredge cutter, knives, drills, weld on extensions, dredge buckets, latch bars, limestone channeling drills, pile driver, wearing parts, pump runner shaft (centrifugal), post hole diggers, sand blast nozzles, screw conveyors, stuffing box sleeves.
6. DAIRIES—Hardface bottling machine cams, fabricate cheese hoppers and buckets, hardface conveyor equipment, weld on cream separator spouts, fabricate or repair filter screens, fabricate or repair floor plates—steel, repair ladle pail hooks, fabricate or repair milk dryers, repair sink frames, repair stands, fabricate or repair tanks, vats, hardface truck trailer hitches, repair vacuum tank, propeller blades.
7. ELECTRICAL EQUIPMENT—Fabricate or repair bases, frames and covers of machinery, circuit breaker boxes, switch boxes, transformer hangers.
8. FARM EQUIPMENT—Fabricate and repair binders, conveyor pulleys, cycle bars, hardface cane shredder blades and knives, chop axe, corn planter shoes and runners, corn shredder tips and knives, corn stalk cutter blades, cultivator sweeps, points and spades, cultivator shovels and spring teeth, disc cultivator blades, drills (seed), feed grinder parts, pulveriser hammers and knives, food choppers, furrowing shovels, hay fork, hay hammers or cutters, hay saws (circular) teeth, harrow disc blades, bar points, harrow gears, harrow shovels and teeth, headers, horse shoes, leveller blades, lister shares, manure handling equipment, mower and shoes, mill hammers, nozzle discs (spraying), planters, plow points, shaves, bar points, discs, post hole diggers, potatoe diggers, pruning shears, rakes, (eccentric, roller and trip), spokes in rims and hubs, rooter teeth, scrapers, scooter blades, subsoiler foot point and teeth, threshing mach. concave teeth, tractors, cleats, treaders; fabricate and repair wagons, clevises, bar irons, water troughs.
9. FLOUR AND FEED MILLS—Hardface alfalfa mill hammers, augers, chute bends, clutch face, corn knives, fan blades, grinder screws, grinding hammers, hammer sides, hay mill hammer sides, pulverizer blades, and pulverizer knives.
10. FOOD CANNING, PRESERVING AND PACKING PLANTS—Hardface cams and knockout finers (auto. filling mach.), bone mill hammers; repair chain links (conveyor equipment), chutes and bends (con-

veyor equipment); hardface crushing mill knives, forming dies (can), grinders; repair pipe and pipe fittings; fabricate or repair sink frames.

11. FOUNDRY—Fabricate and repair annealing boxes; reclaim defective castings; build up charging box, car wheels (worn); hardface coke pusher shoes, conveyor dogs, core machine flights, exhaust fans, ladles, rail hooks, ladles, mixer blades, pump housing (sand), pump housing (pump), sand core cutters, sand plows, sand revivifier paddles, shovel teeth on tips, slinger cups on tips, vibrator frames.
12. MACHINE SHOP—Hardface belt shifter and clutch throwout fingers, bolt and nut machine, guide rolls, boring bar, wearing strip, cam ejector pins, cams and rocker arms, chain links and pins, chuck fingers, clutch fingers and tripper jaws, cranes and crawlers, contact shoes, drill chucks, worn holes, grinder rests, lathe centers, lugs, tool posts and blocks; fabricate machinery bases, frames, guards, covers.
13. MUNICIPAL (CITY) EQUIPMENT IN CONNECTION WITH PARKS, STREETS, ETC.—Hardface ditch digger sprockets and gears, ditch digger teeth, paint guards, power mower shoes, street scrapers, street sweepers, smoothing irons, spreaders (calcium chloride); repair traffic signals ("stop and go"); fabricate and repair bins, boxes, containers; hardface calking tools, cinder loader blades, chutes, sewage ejectors, sewage impellers, tamping bars; fabricate and repair water tanks.
14. POWER HOUSE—Hardface ash conveyor, drag line and link, ash crusher, knocker, ash expeller, multiple set, ash hopper, cams, lifter and valve, cinder loader, fan blades, coal conveyor buckets, coal conveyor bucket lips, coal crusher segments, coal feed dogs, coal feeder screws, coal pulveriser hammer, coal pulveriser mill bull rings, coal pulveriser mill plows and tips, coal pulveriser mill yokes, drip valves, (poppet type), fan housings, (draft), and fan blades.
15. SAND, STONE AND GRAVEL PITS—Hardface cable drills, chain links and pins, conveyor, bucket lips, crusher jaws, plates, dipper lips, dipper teeth, drag line buckets, lips, drag line buckets, runners, drag line buckets, teeth, gravel screens, hoppers, hopper lips, power shovel teeth, latch bars, channeling drills, stone working tools, stuffing box sleeves.

If the advantages of arc welding are properly brought out and presented to the prospective customer, it will be an easier job to sell him on welding service and will result in the job shop making a fair profit on labor. The actual saving to the customer is many times the cost of the service.

What Books to Keep and Why.—As the object of business is to produce a profit for its owner, so the business of bookkeeping is to determine what the profit is and how it was secured, the latter in order that information of value in the future management of the business may be obtained.

The number of special books is limited only by the needs of a particular business. While the rules of the bookkeeper are few and simple, much painstaking thought may be used to good advantage in designing the particular forms and arrangements to make the bookkeeping system fit the needs of a commercial welder or job shop.

Every financial transaction can be recorded in the form of a journal entry. The usual form of journal entry is illustrated thus:

Cash	$100.00	
Sales		$100.00

The arrangement of the journal entry is arbitrary, being the result of experience in attempting to express business transactions in the most convenient form.

	Debits	Credits
Cash in Bank	$ 2,243.30	
Building	8,500.00	
Auto Truck	500.00	
Electric Welders	1,000.00	
Mortgage Payable		4,500.00
Accounts Payable		200.00
Mr.Proper Owner - Capital Account		6,500.00
Notes Payble		1,000.00
Merchandise Purchases	530.00	
Merchandise Sales		840.40
Mr.Proper Owner - Drawing Account	40.00	
Salaries	192.00	
Auto Expense	30.10	
Interest Paid	5.00	
TOTALS:-	$ 13,040.40	$13,040.40

	Debits		Credits
Merchandise Purch.	$ 530.00	Merchandise Sales	$ 840.40
Salaries	192.00	Closing Inventory	560.00
Auto Expense	30.10		
Interest Paid	5.00		
To Balance:-	643.30		
	$1,400.40		$ 1,400.40
		Balance (Net Profit):-	632.30

Fig. 2. Above—sample trial balance; below—sample profit and loss account.

Transactions occur on either a cash or a credit basis. According to this twofold classification the journal is subdivided into two parts, one employed to record cash transactions and the other to receive all other transactions. On the basis of this classification it is customary to subdivide the original journal into two separate books, one the general journal, in which entries for all except cash transactions are made, and another known as the cash journal, or more frequently called the cash book, in which cash transactions only are entered. The two journals required to record cash receipts and disbursements, respectively, are usually combined in one book, known as the cash book, the pages for each alternating throughout the book. Cash receipts are entered on the left-hand page and cash payments on the right-hand page.

The ledger is a record in which accounts are kept. There are two general classes of accounts—real and nominal. Real accounts record assets, liabilities, and nominal accounts record gains, expenses, losses.

A single general ledger suffices only in the case of a small commercial welding or job shop. It soon becomes necessary to segregate certain classes of accounts in subordinate ledgers; the accounts thus treated first are in most instances those with customers (accounts receivable ledgers) and with creditors (accounts payable ledgers). All other class of accounts are set up in what is known as the general ledger. As to rulings, ledgers are standard, and balance. Standard

ruling has two duplicate parts, debits and credits, division line usually being in the center of the page. Balance ruling is a three- and four-column ledger with money columns either at center or at right-hand margin, or at both center and right-hand margin. Extra columns are for account balances. If balance is usually either a debit or a credit, only one balance column is necessary; but if the balance is apt to change from a debit to a credit, or vice versa, both debit balance and credit balance column should be provided. This form of ruling is particularly useful for personal accounts which require that the balance be kept up-to-date.

To balance the accounts is really a very simple matter. It consists merely of footing the debits and credits, finding the amount by which the one side is larger than the other, adding this amount to the smaller side "to balance", and bringing the same amount down on the other side to serve as the new starting point, or balance.

The accounts are now listed as they appear on the ledger, showing the debit balances in one column and the credit balances in another as in Fig. 2. Such a list of statement of ledger accounts is technically known as a "trial balance." The totals of the debit balances must always be equal to the total of the credit balances.

	Debits	Credits
Cash in Bank	$ 2,243.30	
Merchandise Inventory	560.00	
Building	8,500.00	
Auto Truck	500.00	
Electric Welders	1,000.00	
Accounts Payable		200.00
Mortgage Payable		4,500.00
Notes Payable		1,000.00
Mr.Proper Owner - Drawing Account	40.00	
Mr.Proper Owner - Capital Account		6,500.00
Profit & Loss		643.30
TOTALS:-	$ 12,843.30	$12,843.30

Fig. 3. Sample balance sheet after closing.

Those accounts which involve exchanges of unequal money value, that is, losses or gains are now brought together. The bottom illustration in Fig. 2 shows all of the profit or loss items usually found in a commercial welding or job shop set of books, "closed" into the profit and loss account.

Having closed all the loss and gain accounts to profit and loss, we find a credit balance in the latter account. It is necessary now to transfer this balance to the profits or the increase in net worth. By striking or taking off another list of debit and credit balances shown in Fig. 3, there is prepared a "balance sheet", which is distinguished from a

"trial balance" in that the latter contains open loss and gain accounts, while the former consists entirely of assets and liabilities.

Through following the preceding discussion carefully one finds himself in possession of the principals of bookkeeping as may be successfully applied to the average commercial welding or job shop. A good rule to observe is 'never to make the busines fit into a particular bookkeeping system'.

There is an old but nevertheless true saying—that the job is never completed until the account is collected—hence, at times the question of collecting money from overdue accounts is like pulling teeth. One must be particularly watchful to keep his accounts paid up and liquid. Frozen assets prove embarrassing, if not fatal.

Keeping Cost or Cost Records.—Cost accounting is a branch of general accounting whereby the three components or elements of cost—direct material, direct labor and burden, overhead or expense—are calculated for the product made or service rendered in such manner that management can secure accurate and prompt information regarding, and can exercise intelligent and prompt control over, the activities of the business. General accounting shows merely the total profit or loss of the business as a whole, whereas cost accounting discloses the profit or loss on each unit, whether job, special order, product, class product, operation, or process. It is this accounting for units that distinguishes cost from general accounting.

Name ____________ Rate ____________ Period ____________ Check No. ________

DATE		Slip No.	CHARGE	DIRECT				INDIRECT				STANDING ORDERS				TOTAL		
				Hrs	Min	Amount	Pce. Work	Hrs	Min	Amount	Pce. Work	Hrs	Min	Amount	Pce. Work	Hrs	Min	Amount
1	16																	
2	17																	
3	18																	
4	19																	
5	20																	
6	21																	
7	22																	
8	23																	
9	24																	
10	25																	
11	26																	
12	27																	
13	28																	
14	29																	
15	30																	
	31																	
			TOTALS.-															

LESS PAYROLL DEDUCTIONS (Detail) - TOTAL DEDUCTIONS:-

NET PAY:-

Fig. 4. Sample pay-roll sheet.

Probably the greatest advantage of a cost system is that it makes for more effective control and co-ordination of a business than any other mechanism of management. By setting up standards of performance and standard and budget costs for men, machines, and materials, and comparing actual performances and costs with these standards,

a definite conception of the efficiency of the factors in production, distribution and administration is secured. Equipped with cost data, managers are in position to formulate business policies with intelligence and with assurance which comes from the possession of experience.

As a unit or a job progresses in the shop it picks up the elements of cost, namely, direct material, direct labor and overhead. Costs may be divided broadly into two large groups:

(1) Manufacturing or productive
(2) Selling and administrative

In the former group are heat, light, power, wages of employees, etc., in the latter, salesmen's salaries, office expenses, advertising, etc. No attempt is made here to enumerate all items in the two groups. After costs have been classified so as to separate manufacturing from selling costs, they should be sub-classified in order that a maximum of accuracy in recording may be secured. Costs, are, therefore, further divided into:

(1) Direct costs
(2) Indirect costs

Direct costs are payments or charges for labor and material expended upon a definitely determined unit of production or service. It follows that indirect costs are those which cannot be charged directly to the product or job. Indirect costs arise from the following sources:

(1) Indirect material, such as wire brushes used in cleaning up a finished job, or new tools used to replace those discarded.
(2) Indirect labor—for instance, wages of foreman who supervises the various shop employees (other than specific jobs he may elect to handle himself).
(3) Fixed charges—depreciation, taxes, insurance, etc.

Before costs can be properly recorded and intelligently controlled, the right basis of costs must be established. More cost systems fail because wrong bases of cost have been established than for any other reason, because they lead to incorrect costs.

Requests for purchases should originate with the shop foreman, on the office.

The chief record used in the receiving or stock room is the receipt voucher which should be issued in duplicate—one copy is sent to the office for checking the quantity on the invoice and the copy is retained in the stock room where it is filed after posting the receiving information to the stock ledger record.

Accounting for labor in the shop, pay-roll, office and in connection with overhead charges or costs, should have the following objectives:

(1) To determine wages due each worker in order that pay-rolls can be prepared, and so that no worker will be paid more than he has earned.
(2) To determine labor costs by units, operations, etc., so that proper direct-labor costs can be entered on cost sheets.
(3) To obtain data for calculating overhead expenses.
(4) To procure information for proper control of labor costs.

The time card is the essential form used to reach the foregoing objectives.

The basic record in pay-roll work is the pay-roll sheet, a copy of

which appears in Fig. 4. The slip numbers are the number of the time cards of the welders. The charge column shows the order numbers to be charged for the work done by the welders. Day-work and piece-work wages are entered in the "amount" and "piece-work" subdivisions of the "direct" column, respectively. The same is true of the "indirect" column. The "total" column shows the total earnings of each welder for each day. At the end of the pay-roll period, all columns of the pay-roll sheet are footed vertically and cross-footed to agree with the sum of the total column. If the work checks, it indicates that it has been done accurately. Deductions, in behalf of the employees, are entered to get each welder's net pay for his pay envelope.

At the end of the month the pay-roll account is credited on the general ledger and the work in progress account is charged on the general ledger, for the grand total of the direct labor shown on the pay-roll sheets, and the proper departmental overhead accounts are charged on the general ledgers for the indirect labor. In the office, time cards for direct work are charged to productive orders; and those for indirect work are filed behind the standing orders.

The final steps in cost accounting as applying to the job welding shop is the preparation of cost reports and financial statements, such as expense and burden statements, cost of sales analysis, monthly report

	Jany.1 to May 31st, 19 38	Month M A Y 19 38	Month April 19 38
TRUCKING EXPENSE:-			
G-101 Maint.of or Supplies for Tr.			
G-102 Labor			
G-103 Road Expense			
G-104 Hired Trucks			
G-105 Miscellaneous			
Total:-			
APPORTIONED CHARGES:-			
Depreciation			
Light & Power			
Liability Insurance			
Miscellaneous Overhead			
Total:-			
TOTAL EXPENSE:-			

DISTRIBUTION FOR MONTH	Percentage %	Amount $
1. Company Trucks		
2. Hired Trucks		
TOTAL EXPENSE:-		

Fig. 5. Sample expense statement.

of sales, inventory statements, balance sheets and profit and loss statements.

One of the most important sets of cost reports are expense and burden statements in which indirect costs are entered. A sample form of expense statement appears in Fig. 5. A sample form of burden statement appears in Fig. 6.

Another valuable report for executives is the "cost of sales analysis"

WELDING DEPARTMENT BURDEN STATEMENT
Month ______________
Year ______________

I T E M	Stand. Order Code No.	Normal	This Month	Last Twelve Months
INDIRECT LABOR				
Foreman and Asst.	1-100			
Inspection	1-101			
Handling Product	1-102			
General Labor	1-103			
Miscellaneous	1-104			
TOTAL:-				
MAINTENANCE				
Machinery	1-110			
Buildings	1-111			
Tools	1-112			
Miscellaneous	1-113			
TOTAL:-				
SUPPLIES				
Small Tools	1-120			
Oils and Waste	1-121			
Miscellaneous	1-122			
TOTAL:-				
PROPORTIONED CHGS.				
Depreciation	1-130			
Taxes	1-131			
Insurance	1-132			
Light & Heat	1-133			
General Expense	1-134			
TOTAL:-				
GRAND TOTAL:-				
No. Direct-Labor Hrs.				
Standard Burden Rate				
Burden Applied at Standard Rate				
Balance (difference between actual & applied) to Profit & Loss Account				

Fig. 6. Sample burden statement.

prepared monthly. This shows the monthly cost of all jobs repaired. The analysis should be kept according to classes of jobs handled. It is possible, then, to determine the average percentage of profit by class of jobs, which is of great value to executives.

If the cost of sales analysis shows only costs and not sales prices, a monthly report of sales should be prepared. A serviceable form of this report follows: Item, this month; estimated this month; per cent increase or decrease, last month; per cent increase or decrease, todate this year; estimated todate this year; per cent increase or decrease, todate last year; per cent increase or decrease. The management by studying this record can effect a better control of sales than without the record.

The foreman should also be kept informed as to the status of inventories as reflected on the balance sheet. An inventory statement may be prepared monthly which shows the control accounts for the inventory; raw materials, supplies, work in progress, and finished jobs; figures for the current month, the last month, the year to date and the corresponding month last year being entered on the statement. These inventories are scrutinized by the management to see if the values or stocks carried are too high or too low.

Another monthly statement of value to the management is one which shows the additions to the plant control accounts according to the classification of equipment. These represent the fixed assets. By a close watch over proposed expenditures for plant and equipment, large sums of money are saved, because it may be discovered that some of the proposed additions to plant and equipment are not vitally necessary to successful operation of the commercial welding or job shop.

Inventories and Inventory Controls.—The main object is to handle the greatest possible volume of business with the least practicable investment in stocks. This involves consideration of turnover—the rapidity with which stock can be moved—thus avoiding unnecessary tying up of capital invested in stock. Shortages must be avoided. They cause delays in completing repairs and in making deliveries and result in dissatisfied customers.

It is first necessary to determine what the running inventory is to include. In the commercial welding or job shop it includes in general, the stock of electrodes or welding rods, oxygen and acetylene and such other items of supplies which are indispensable to the productive process. There must be a thorough going system of stockroom control to prevent withdrawal of stock without proper entry upon records. The stockroom should be located where it will be most accessible to the shop proper.

The forms recommended to be used depend upon the size of the welding business. In the average size shop the essential forms are a bin tag, a requisition, a receipt voucher, and a perpetual inventory form. Some of these forms are shown in Fig. 7.

B I N T A G

ARTICLE ....
SYMBOL ....
MATERIAL ....
MAXIMUM ....
MINIMUM ....
LAST REQN..........
....

STORES REQUISITION

CHARGE JOB NO:		Delivered	
WANTED QUANTITY UNIT	DESCRIPTION:	Amount	Unit
REMARKS:-		Price	PER Unit of Dely
		Total Value	
Written by: ____ Date ____	Approved by: ____ Date ____	Material Recd. by:-	

LOCATION IN STORES	ISSUED	BY DATE	EXTENDED	CHECKED	STORES CREDITED	ACCOUNT CHARGED			

S T O C K R E C O R D

Article ________ Maximum ________
Symbol ________ Minimum ________

Ordered			Received			Withdrawn		Balance
Date	Reqn. No.	Amt.	Date	Reqn. No.	Amt.	Date	Amt.	

Fig. 7. Sample forms for inventory control.

Pricing Work.—The consensus of opinion amongst commercial welders or job shops is that there is entirely too much price cutting with very little effort made to seek a remedy. Furthermore, very little effort is made in most localities to organize job shops and their welders for mutual benefits including standardization of price schedules. The authors of this article are not attempting to solve the problem but merely to offer practical suggestions which may or may not prove prac-

OPERATION COST RECORD

Date:- ____________

Job - ______________________________

Weld Dimensions ______________________________

Work Done By - ______________________________

	ELECTRODE "A" Amt.	ELECTRODE "A" Rate	ELECTRODE "A" Cost	ELECTRODE "B" Amt.	ELECTRODE "B" Rate	ELECTRODE "B" Cost
MATERIAL (Include Handling Charge: ELECTRODES REQD.						
LABOR (State if Welding or Grind)						
POWER REQUIRED:- KWH						
OVERHEAD:-(Include interest, deprec maint. supervision..........						
TOTAL COST:-						

TIME JOB COMMENCED:

TIME JOB COMPLETED:

TOTAL TIME.........

BALANCE IN FAVOR OF ____________ AMOUNT SAVED ______

Above Data Recorded by:- ______________ Checked by:- ______________

Fig. 8. Sample operation cost record.

tical in the working out of the commercial welders or job shops in certain localities as affecting organization and standardization of price schedules.

In order to price work it is first necessary to determine the most economical electrode or other material to be used. Where any question arises as to the most economical electrode for securing results, it is suggested that tests be run to record time and material for two or more electrodes, for the purpose of comparison. Fig. 8 is offered as a suggestion for recording the time and material used on two alternative electrodes.

It is suggested because of the completeness with which this subject has been dealt with that reference be made to the "Procedure Handbook of Arc Welding Design and Practice" for estimating costs of welded joints, and for procedures, speeds and costs for welding mild steel.

The following general price schedules on hourly basis have been reported and found to be existing in a large section of the Southeast where agriculture and textile industry predominates:

Shop work (other than hard facing):
  Labor and material, \$3.50 per hour.
Shop work (hard facing):
  Labor, \$2.25 per hour plus material.
In the field—labor (welder) while operating, \$4.50 per hour.
  labor (helper) while operating, \$1.25 per hour.
Traveling time of welder, \$2.25 per hour.
Traveling time of helper, \$1.00 per hour.
Mileage for car and trailer (portable equipment), 6¢ per mile.

ORDER FOR WORK

No.__________

Mr.__________ __________193___	Bolts and Nuts Sizes and Number	Wrought and Cast Iron Weight in Lbs.	Brass, Steel, Babbitt Metal	Time in Hours

____________________Foreman

Fig. 8. Sample order for work.

The foregoing labor figures take into consideration the cost of the electrodes per pound, power bill, depreciation and maintenance of the electric welding equipment, shop overhead, stores and office overhead, welder's time, helper's time (as indicated), plus a legitimate profit, depending upon the size of the job.

Where much of the work is handled by more than one man, it is well to originate an "Order for Work", see Fig. 9, on which is inserted and issued in duplicate, the Shop Order No. and the order for work is issued to the welder by name and the order is dated. A description of the work to be handled is incorporated in the body and the captions may be changed to suit the welding department.

In Conclusion.—The past year has seen the actual preparation in the arc welding industry for a sound prosperity in which low manufacturing costs, and then higher profits and certainly greater volume of sales, are being made possible by a more extended and more intelligent application of arc welding.

A good slogan for the progressive commercial welder or job shop should be "If It's Metal, We Can Weld It". And if every job that is offered is produced and turned out in workmanlike manner, in accordance with the principals of good business as laid down in this article, a fair margin of profit is assured the owner.

Chapter II—How to Use the Arc to Increase Business in the Garage

By E. W. WEINBERGER,
Owner, Weinberger's Garage, Mott, N. D. Complete paper contained 18,000 words, 140 photos and numerous illustrations.

There are two electric arc welding machines in the automotive repair shop I own and operate. One is driven by the "high line" and the other is a portable unit driven by a six cylinder car motor. Before I tell how these machines are used to increase the profits of our repair and maintenance operations, I want to describe the shop; the community and the town where the shop is located. I want to tell of my start in the repair business also.

The shop is fifty by one hundred feet, of brick and tile, located in a town of about 1200. The trade for the shop comes from a wheat farming territory surrounding the town. Work on cars, trucks and tractors, form the bulk of the business for the garage. No cars are sold by this garage.

There is about $9,000.00 worth of equipment in the shop, including a valve refacer, valve seat reamers and grinders, hoists for brake and lubrication work, a power car washer, complete facilities for cleaning and repairing radiators, complete electrical equipment including a test bench and motor analizer, complete front axle equipment including the rack to drive the cars upon, brake relining machines, magneto testing and repairing equipment, battery charging and repairing equipment, reboring machinery. The welding department has an acetylene generator, two torches, portable grinders, a preheater, a stationary grinder in addition to the arc welders. A good supply of iron and welding rods are kept for the arc and the torch.

There are five other garages in the town. Two shops are larger than the one I operate. There is also a large modern blacksmith shop, which has an arc welder.

When tractors became the style in farming operations, I found that I was out of date in methods and equipment for handling the welding jobs which came into the shop. Power drills, harrows, binders, combines, and the tractors themselves, contributed a different kind of welding than we were accustomed to doing. There was something lacking in the shop for we had to admit that we couldn't repair a large casting from a tractor, without dismantling and preheating. The labor involved in the removal and assembly of the broken parts, wasn't the worst part of the procedure. Loss of even a little time meant more to the farmers now because of the heavier investment and lost acreage. It was up to me to get some item of equipment that would not only do the job with less labor, but which would save time in the repair of this new heavier type of farm machinery.

Arc Welder Good Investment.—An arc welding machine has

proved the best investment I have ever made in any equipment for the shop. I could barely make the down payment; but I got the machine, and a good supply of welding electrodes. I spent almost three weeks of continuous practice with the arc before I used it on a job. Learning how to use the machine—particularily on the overhead jobs and vertical work—has paid me dividends ever since.

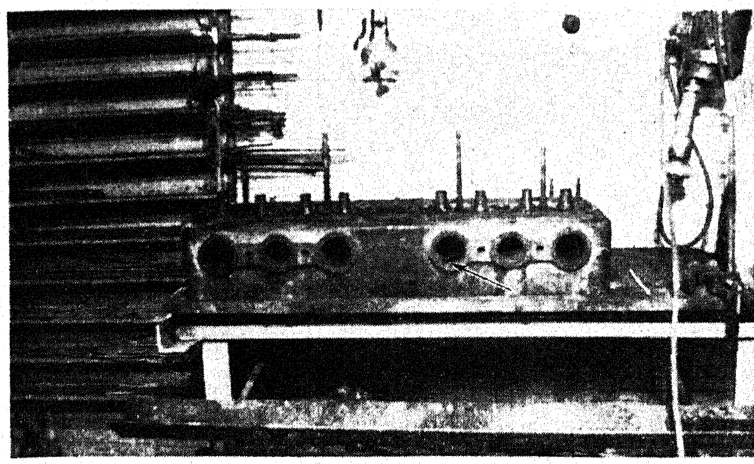


Fig. 1. Hole in exhaust port before welding.

The first car job was on a Master Buick, cracked the full length of the block, with the whole side out. After taking off the manifold and welding the smaller pieces together, I started welding in the large pieces. The job took all day, but I had no trouble with the arc; the time I had spent in practice was already paying dividends! I remember that the electricity and rods did not cost me $2.00 and I got $35.00 for the job. Afterwards I felt that maybe I did not charge enough.

I never imagined so many things could freeze up in this country as did freeze up the first winter I had this welder. $500 was an average month for the welder alone, and I sometimes went as high as $700. The rest of the business increased in proportion.

A four-cylinder truck came in one day, with the motor in good shape, but the two center cylinders were cracked down the inside of the cylinders from the top for a distance of about two inches. It occurred to me immediately that I could weld the cracks on this type of motor, without dismantling, (except for the cylinder head being off), by drilling holes in the outside of the block, opposite the cracks in the cylinders, and taking out a piece of the outside of the block, so that I could weld the cracks from the outside. I cleaned the scale and rust around the cracks, and did the welding job in about two and one-half hours and got $10 for the job. The welds were well reinforced and they never leaked a drop, and as far as I know, the motor is running yet. The piece, that was taken out of the side of the block was replaced of course, after the inside weld was made. The customer was not

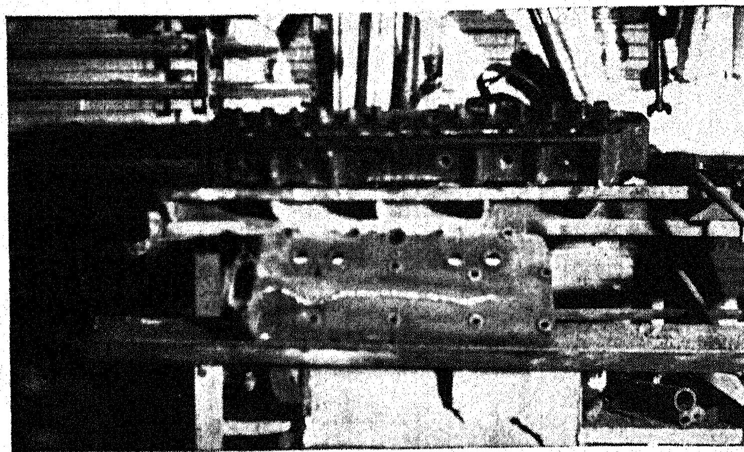


Fig. 2. Crack in frozen cylinder head arc welded.

deprived of the use of the truck. He was saved a considerable amount in the above method of repair compared to any other procedure. The unusual type of welding job is made more feasible by the arc's use. Figs. 1 and 2 show arc welded cylinder block and head repairs.

Continued use of the arc brought the discovery of added uses at a pronounced increase of profit over other methods of repair. For instance, some of the older delivery and other trucks would have the front axles sag, so that the front wheels wore out bearings quickly; were hard to steer, and wore out tires in a hurry. Two iron rings were fastened in the concrete in the floor, spaced about the right distance for bending axles without removing them from the car. When the axle was straightened, it was suggested to the owner to have the axle re-enforced.

I strengthened many of these axles this way. I would measure the distance between the two axle bolts, cut off a piece of mild steel the above measured distance, the steel piece being as wide as the axle, about 1¾ inches wide and about 7/16 or ½ inch thick. The steel was tacked on the bottom side of the axle. As the welding progressed near the end of the axle the mild steel became hot enough to bend up easily to the shape of the end of the axle; a hammer did the trick in bending it. The mild steel was welded on the front and rear sides for the entire length of the axle. When the piece of steel was placed on the bottom of the axle the depth of the axle was increased by almost an inch. None of the axles re-enforced in this way bend again no matter how much abuse they receive. The job cost the owner $6.50 and took about an hour to do.

Many Unexpected Jobs.—Lots of times jobs come in that a fellow never thought existed; but when they come in, you think of the arc, and the job is practically done! For instance, a friend of mine bought a large trailer house. He had an extra leaf put in the rear spring of his

Fig. 3. Arc welded plate re-inforces truck frame.

Packard, and a hitch made for the trailer. The mechanic doing the spring job could see no permanent way of holding the rear set of spring clips in place on the springs. They would work backward on the springs, cause a very pronounced knock and rattle, and the owner always thought he was in danger of breaking the springs because the clips were not in place. I took the welder and dabbed a few little spots of metal on the bottom of the spring leaf. The spots of metal made it impossible for the clip to work past these places. Then I tacked the bottom corners of the clip to the side of the spring leaf. This job did not take two minutes! It did not mar the spring nor any of the leaves; and there was no doubt in the owner's mind that the clips would stay in place. He asked me how much the job was and I said, "Fifty cents." He handed me that with a grin and said, "It's darn funny but that is less than I paid any of those other birds to work on these clips, and then to think I had to come home to get them fixed. You may as well do a few other things," he added. We washed and greased the car, then polished it and waxed the top, changed the oil and tightened the body. Two minutes of my time did the spring job; but one mechanic was busy for a day and a half as a result. I had never thought of tacking a spring clip in place; but until then, I had never seen a clip that defied several mechanics to dare keep it tight. My first thought was that the arc would not fail on this job and it didn't. I could cite dozens of similar instances where the jobs we got after doing a minute or two of arc welding on the car, kept the shop busy for days. Once we welded a broken frame and received $135 for a motor and clutch overhaul! Fig. 3 shows a truck frame reinforced by arc welding.

We used spare time in the shop to build and fabricate all kinds of shop gear and equipment. Using an old jack screw and a few pieces of scrap iron we made an arbor press which we use every day. It did not cost us over $5.00 for the time and material, but we could not

have purchased it at that time for less than $50.00. The shop is full of smaller items which we made with the arc and are using every day. We found that the strongest wrenches we had were not capable of loosening and setting the nuts on tractor main bearings and connecting rods. After buying and breaking some of the heaviest wrenches made, we made tractor work as easy as car work by using the arc. We bought the heaviest sockets we could buy and welded them to old rear axle shafts. These made L wrenches and T wrenches with plenty of leverage. The arc machine saves us hundreds of dollars every year, figuring time only in making of special tools. (See Fig. 4).

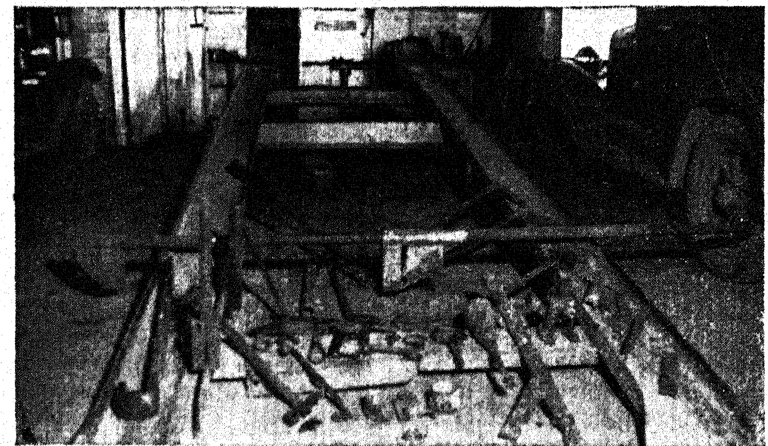


Fig. 4. A few special tools made from scrap with the arc.

The next spring after we got the welder, a farmer brought an Allis-Chalmers tractor block in, which was cracked near the front end. The repair job cost the owner about $165.00. A new block, if I remember correctly was approximately $500.00. This job was in the shop about a week. I worked at it at odd times, and in the evening. The rods used cost less than $5.00 and the current about the same. The arc certainly made this job possible and profitable.

It was in this same year, 1927, when we discovered the value of the arc in reclaiming worn shafts of all kinds. A shaft worth $30.00 could be welded and turned down for about $6.00, an hour's welding and lathe work doing the job.

We found that we could make better welds in heads which were cracked in the exhaust ports, by heating them first in the forge or with the kerosene preheating torch. The first bead run on the crack should be hot, using a small rod, to get penetration through the crack; then there is no danger of the head warping or checking. I have done any number of jobs in this manner, welding across a valve seat that was cracked, and always have been able to use regular valve seat reamers on the seat. Electrodes suitable for making machinable welds are used. The job can be done quicker, certainly cheaper, with more profit to the shop, and one does not suffer from the heat, as one does

with the torch. Men from distant towns are sent here by their local welder, to have this or that job done with the electric arc.

Some of the older cars had a radiator shell, which was in separate pieces at the bottom, being held together by a hinge affair. On the rough roads these would break off, and the radiator would develop bad leaks. We took 1/8 by 1/2 inch mild steel and bent it around the bottom and inside of the radiator shell, and welded the iron to the shell. We had quite a run for several years reinforcing these shells; and this also gave us opportunity to do radiator repair jobs. We got $3.00 for welding and it saved the customer more than that in radiator repairs.

Instead of taking off the broken engine hangers from the Ford T pan, we found that we could do a better job than installing a new one by welding the old hanger right in the car. They cannot be welded by the torch in the car, because the gaskets would be burned up. With the arc, welding a little at a time, the gaskets were not affected. We weld the broken front crossmember on the V 8 Ford in the same manner that we developed on the Model T. We run a hot bead over the length of the crack, and lay a piece of old truck frame which has been cut to the width of the crossmember, having it project about six inches on each side of the crack. This piece of frame is then welded the full length of the sides of the crossmember. This repair takes less time, and costs the owner of the car less money. These are just a few extra jobs we do at good profit because we have the arc.

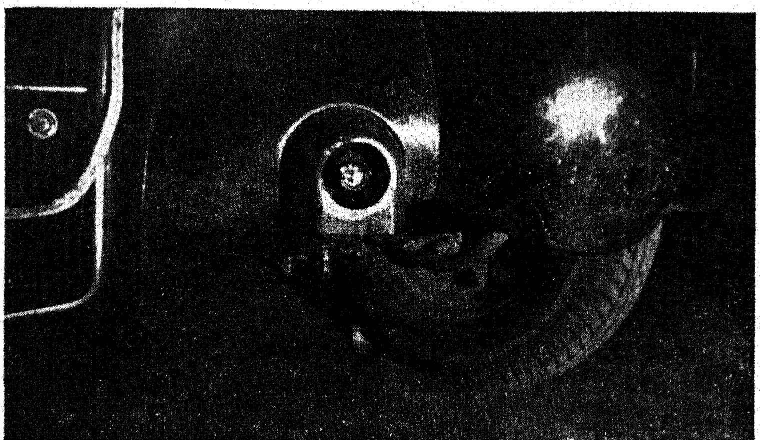


Fig. 5. Arc welding is handiest means of removing broken studs.

Using the arc on little jobs like taking broken studs out of exhaust manifolds, car and tractor blocks, bumper cap screws, (See Fig. 5), and great variety of other places, fascinates the customer not only by the novelty of the operation and great saving of time, but because his own amateurish efforts at this type of repair work have demonstrated the futility of using haphazard methods of extraction. Despite new gadgets constantly appearing on the market, our answer to this age-old

riddle of industry remains our standby—the arc. In our many and varied experiences, we find that it offers the quickest and most efficient method of solving these vexing problems.

Take a washer that just fits over the broken stud. If the stud is broken off below the surface, lay the washer over the exposed stud hole. Strike the stud in the center, and when you have a good arc, work it around to the outside of the stud. With a little practice one can do this without welding the stud to the threads. The washer will get white hot almost immediately. Let the washer cool, lay another washer on top of the first one and weld to the one below. After letting this cool, build up the washers in the center. The heat from the welding travels down the stud and expands it; this action squeezes the threads and when the stud is cool, it can be turned out easily. The threads always come out bright with the rust burnt off, and in perfect condition. Washers may twist off without bringing the stud but that does not matter because more heat will loosen it. Put on some more washers and weld the stud longer this time until the stud is loose before starting to turn it out.

A little practice with this method of taking out studs will give a fellow confidence, and then he knows before he starts which one is going to be hard to extract.

The average car owner gets few opportunities to watch the electric arc. Whenever a shield is offered him, he watches the job and is greatly impressed. Didn't he see you weld with his own eyes? Later, this inspires confidence in your ability and he is more than willing to have you make other repairs on his car.

On some cars and trucks, the front motor supports give a lot of trouble on gravel roads. The later models have rubber pads under the motor brackets. These become oil-soaked; the brackets work loose, and if allowed to remain loose, the bottom of the front motor bracket will wear completely out. At the same time it will do a lot of damage to the front crossmember and radiator. When it becomes necessary to tighten these mountings, it is usually found that the nuts on the bolts or studs holding the brackets to the crossmember, cannot be turned because the bolts turn in the bracket. The older models had studs which through vibration spoiled the bracket threads and then these stud nuts could not be turned for there is no way or provision made to hold them. In the majority of cases the radiator must be taken off in order to put in a new bottom motor support or repair the crossmember, but this does not solve the problem of holding the loose studs or bolts. Welding the top of the studs to the bottom of the mounting bracket, will make the nuts easy to turn. If the crossmember and bracket are not in good shape, the nuts can be turned off and repairs made on the crossmember or bracket. When the bottom of the bracket is broken out, or worn so thin that it should be replaced, we put in a new piece of mild steel and weld it in place with the arc. Welding this bracket in place on the motor could not be done with the torch because the front main bearing and the gasket for the timing gear case cover would be destroyed by the heat.

Generally a leaky radiator calls the owner's attention to loose motor

bolts. While the radiator is off, we show the owner how easy it is to repair the motor supports. In this way we have two jobs instead of one. If the radiator has been leaking for a long time, the chances are good that the radiator hold-down bolts and nuts will be rusted and frozen. If this is the case, you can not tack the top of the bolt very handily, but you can burn off the end of the bolt and nut at the bottom of the crossmember and have the radiator removed in a few minutes. If the bottom of the radiator shell happens to be broken, the job of removing the nuts from the bolts is all the more difficult, when working by hand. When a mechanic is working on flat rate it is important to save every minute possible because a lot of flat rate operations are hard enough to beat without delays with frozen nuts and bolts.

The arc can be called on in many ways to complete plans for labor saving methods in any kind of car work. Not long ago a car with stripped ring gear and pinion teeth was brought into the shop. The rear springs have to be loosened, the universal joint taken apart, and a lot of little jobs must be done before the drive shaft pinion can be pulled out. We usually weld a nut, the same size as the driveshaft pinion nut to a long bolt with three or four inches of threads. After a piece of heavy plate has been added, we screw this nut and bolt onto the end of the driveshaft, allowing the bolt to project through a heavy piece of plate which extends across the opening in the differential housing. A nut is placed on the projecting bolt on the outside of the plate and the assembly is used as a puller to remove the driveshaft without removing the rear axle housing from the car. The end of the driveshaft on this car was broken off and we had nothing to fasten the bolt to to pull the shaft. We decided to weld a long bolt to the end of the driveshaft and pinion. We welded a 3/8-inch bolt on the pinion first and broke it without pulling the driveshaft; so we welded a 1/2-inch bolt to the pinion and pulled the driveshaft easily. The use of the arc in this particular job, saved the shop five hours of labor and netted $12.00, the flat rate for this work. The mechanic also was paid according to the flat rate. This example of how the arc saves time, shows that the mechanic and shop using the arc in every day repair work make more money on each job than they otherwise could. More jobs can be finished in a day. The deduction from the premise of more jobs per day is obvious.

Another valuable use for the arc in the automotive shop is tacking parts in place to keep them from loosening. After a hub is pressed on a new water pump shaft, tack the hub on to the shaft. It is no trouble to grind the weld off when a mechanic wants to remove the hub, and yet the tack weld makes it impossible for the hub to work loose and into the radiator thus doing a lot of damage. The using of the arc for a second or two, tacking obstinate nuts or bolts frequently saves hours for the shop. If the owner of the car is waiting and a couple of men spend considerable time on a stubborn nut or bolt, he gets the idea that these men are inefficient.

Tacking with the arc weld is just as valuable in some of the new truck assemblies. The pins, holding the brake shoes in place, work out completely after the lock-rings fall out of the pins. A tack weld on the pins and shoes insures the shoes from coming loose and ruining

the brake drums, shoes and carriers. A portable grinder can grind off the weld whenever a mechanic wishes to remove the shoes. A comeback job on one of these brake assemblies, because of a lock-ring working loose, may cost the shop $15.00 to replace and repair. Making tack welds on this type of job costs us less than 1/4 of a cent!

Another part it pays to tack weld is the differential case on the average car after making repairs. The differential pinion gear shaft works loose in the case and if and when the small lock pin shears off the pinion shaft, it comes out and invariably ruins the whole assembly, case, ring gear and pinion, and sometimes the rear axle housing itself. We tack the pinion shaft at each end, to the case, and save the customer future unnecessary expense and a possible comeback to the shop.

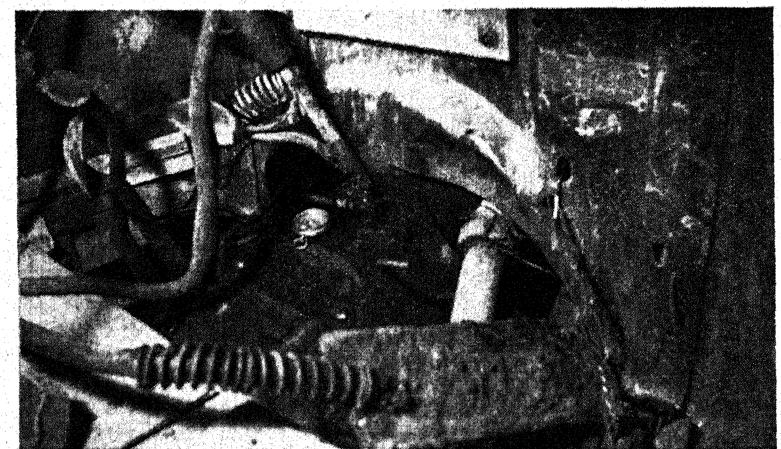


Fig. 6. Connections of arc welder for charging magnets.

Magnet Charging.—Another common use for the arc machine, which boosts the reputation of the shop for ability to really be able to do things, is recharging magnets on the old model T Fords, (See Fig. 6), and Fordson tractors. There are a lot of them in the country still. The magnetos are easily recharged with the D. C. arc generator. All one needs extra for the job is a good compass. The compass is held near the magneto plug or terminal, about an inch away and to the left of the terminal. Have someone turn the engine with the crank until the compass N pole points towards the front of the engine. Connect the positive lead from the arc machine to the magneto terminal after the lead that runs to the coil box is removed. Set the amperage of the arc machine on low, and with the generator in motion, drag the other lead from the welding machine along the frame of the car or tractor for a minute or two. I generally set the voltage on the welding generator as high as it will go. This is not necessary, but as it is the jolt or voltage that makes the most impression on weak magnets in recharging them, I like to give them a real jolt. We get many of these magnetos to recharge while the motors are being overhauled. In this case

all we need to do the job, is the flywheel and the magneto field coil assembly. We receive $1.50 for this job and $2.50 for the job when done with the motor together. I always have a waiting list of Fordson owners who have asked me to stop in at their place some time when I am out with the portable welding outfit, and happen to be anywhere near them, and charge the magnets on their tractors. Nice work when you can get it: and you can get the work with the arc machine!!

Having a shop in a community with an arc machine has other advantages. The arc helps to build up the community directly. A man cannot come here and get something repaired and wait any length of time without spending money in other places of business. This certainly helps to build up the town. This man invariably tells the other business men how fortunate the town is to have a good arc operator. He also says that he likes our town. This makes a good impression on the merchant. He in turn makes his place of business better. Other business men make their places of business better than the businesses in the neighboring towns. Then you have the makings of a real community.

Using the Portable Welder.—When the work coming in from the neighboring towns, seems to be falling off, I use the first slack day in the shop, to go out in the portable welding outfit and visit nearby towns. I find out if I can, just why the work is falling off. The welding machine attracts attention standing on the street in a strange town, and creates a lot of conversation about arc welding and about our shop. It also sells the local shop on the idea of using our welding service on jobs which it can't handle. On all of these trips I manage to do some kind of welding job in one of the shops. I have waited for a number of the shop customers to go home and bring their car or something they wanted to have welded into this shop where I had the welding machine. If the job is a small one I never make a charge to the shop, but always collect the price of the welding and give the money to the shop. This creates a very favorable attitude towards us. In fact I know it makes them feel anxious to send us a job in the near future to repay us for the small favor shown them while in their town. We plan to do this in the same way we would do any other kind of advertising. It may cost us a little money to do this sometimes, but what kind of advertising doesn't cost. We carry placards in the welding outfit advertising our services. We ask permission to hang one of these placards in the shop, and as long as they are not doing the same kind of work, there is never any objection.

The arc is the best tool we have in the shop for removing and replacing turret car tops. To remove a top, the torch is used first to cut the old top away—about five inches away from the factory seams. The main section cut out by this manner is removed. There is now about five inches too much top left all around the edges. We take a piece of old spring leaf about two feet long and weld this to the rear and side of the extra strip of the top at right angles to the seam. The spring leaf is turned with a monkey wrench and the extra top metal comes off the body at its seams, just like opening a tin can with a twisting key. The new top can be replaced in this manner in less time, and then if

the seams are arc welded there isn't as much warping as though one used a torch.

Banged in panels and fenders that are difficult to reach from the inside to straighten are easily patched by means of the arc. Simply cut a piece of body metal to the desired shape and contour and weld over the stove-in place, around the edges. Sand off the weld with the portable sander and refinish in the usual manner. This is another short cut one learns to use when he has an arc machine.

Every truck we rebuild from a wreck usually brings us an extra job of fish plating the frame to strengthen it. The frame needs this anyway, because if the truck is rated at a ton capacity, the average owner will haul three or four tons.

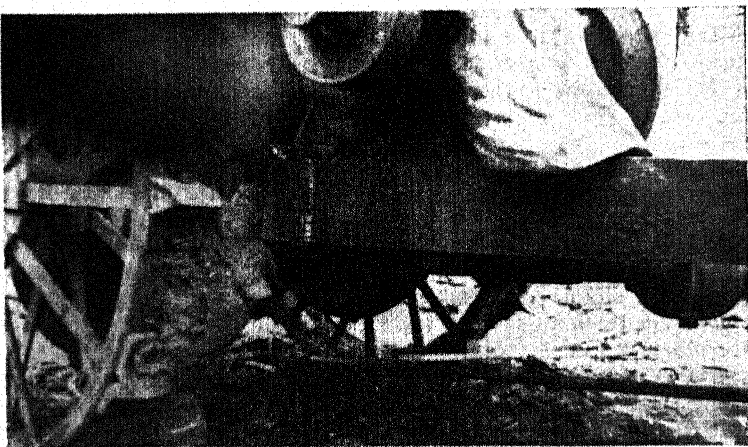


Fig. 7. Tractor frame repaired by arc welding.

As each spring rolls around, the farmers are getting ready to go into the fields, there are always a number that come in to have generators and lights put on their tractors. One tractor can be made to do the work of two, by running day and night. The installation of old car headlights or a floodlight, makes night work with the tractor efficient and practical.

We must build various brackets to hold the generator and lights in place. It is virtually impossible to secure these brackets without using the arc. We use the arc to do all the building and installing of these tractor lights. Twenty installations and no complaints, is another victory for the arc! The average installation including an old car generator, car light, wire, switch, and labor and welding, costs the owner about $35.00.

Profitable Farm Machine Repairs.—The arc is especially valuable and useful to farmers during the rush seasons of spring and fall work because of its ability to repair and maintain machinery. Any breakdown, no matter how small, costs the farmer money and loss of time. In a case of delaying operation of a particular unit for a day or two,

the cost of the shutdown may run into thousands of dollars. A galled clutch bearing race, for instance, may defy the efforts of three or four men to remove by hand. I have made several trips to cut out galled races and similar items and do the job in a minute or two. The position of the frozen bearing may be such that suitable pullers cannot be used in the field. There is always room enough to enable one to use the arc successfully. Arc cutting of bearing races is a common shop operation. It is fast and doesn't heat adjacent parts. During the rush seasons, we use the arc to repair silage cutters, combines, feed mills, and other items on the farm.

Fig. 8. Tractor motor flywheel arc welded.

The bulky parts of a tractor frame, wheels, hitches are always welded without removing. It is cheaper for the farmer to have us go out and do the welding at his farm, than it is to dismantle the tractor, plow, combine and other heavy equipment. We can make the trip quicker than he can dismantle the parts. We make more money making these trips than we would if the farmer brought the work to town. Fig. 7 shows a broken tractor frame welded at the farm. Fig. 8 shows a flywheel repaired.

Most of the farmers have some kind of trailer. They use them about the farm, even hauling grain and coal. To pull these trailers safely and without damage to the car, they have to have a good hitch. Three or four dollars puts on a good one, and the arc is used to do the most of the work. We raise the car on the lift, and do the fitting and welding in comfort. These jobs are the more profitable because we have the arc to use; danger from fire is lessened and it is more easily done. Also the job is better and costs the owner less than any other method.

I must not forget to mention the use of the arc, in hard surfacing. Lister parts, duck foot cultivators, drag line shovel teeth, magneto impulse catch plates and pawls, and road machinery of all kinds, plow-

shares, and other articles too numerous to mention, come in the shop for an application of hard surfacing material. Fig. 9 shows splines on tractor axle shaft built up by arc welding.

The owner of a garage and all the mechanics should take as much part in the public matters as possible. Anything beneficial to the community will also benefit the garage. Active and energetic business men lay the foundation for substantial growth in the community, and this means the more opportunity to enjoy a growing and prospering business.

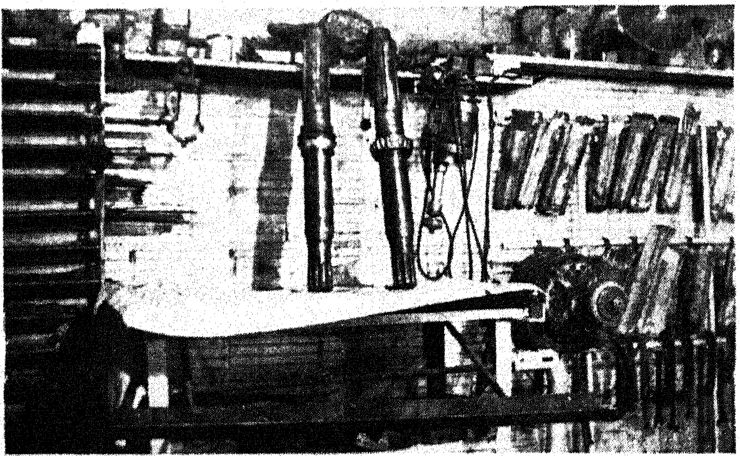


Fig. 9. Tractor axle shaft splines built up by arc welding.

The owner of the garage should also hold regular meetings of the employees and himself. At these meetings he can instruct the mechanics how to do their work and what to say to the customers. Here is also a good time and place for the airing of little grievances that the men may have against each other, or against the owner. After a few of these meetings, the men will be found to have thought of something for the good of the shop, and can hardly restrain themselves in the telling of the idea or suggestion. They are made shop-conscious for our benefit and they also benefit.

Our meetings generally wind up with a lot of sales suggestions to sell this or that service. We know the essence of good salesmanship is in giving the customer what he wants, but we also know that the shop may be the best in the world and not get any place if the mechanics are not selling the shop and themselves. The selling mechanic knows that a little chin music directed at the customer will coax more dollars into the cash register than hours of tinkering with a wrench and screw driver. The good mechanic must learn to be a mixer, a merchandiser, as well as a repairman. The men are more than willing to do their part when they find the boss has his problems too, and find out what he is trying to do to solve them. They know what is good for the shop will put money in their own pockets.

Keeping the Business Growing.—I shouldn't omit the obvious things necessary to keep a business growing. Keeping the place clean, having a clean rest room, keeping a strict watch over the credit accounts, paying your own bills, courtesy, are a few of the things the owner and the mechanics have to watch every day. A proper display of merchandise is essential, also. The amount of stock carried, I think, is determined by so many local conditions that it is impossible to give much direction in this phase of the business. Certainly the common things called for by the customers, should be carried. If you cater to the carburetor service, you must have a good assortment of carburetor parts, and so on. Shop supplies should be watched all the time, so that the common things used in the shop every day are on hand. No mechanic wants to walk a block or two when he is busy, to get a bottle of shellac, or some similar item that should be in the shop.

All shops have to have some way to determine profit. I don't think our method is much different from that used in most any business. The first thing to do to figure profit, is to find out how much a certain job costs you for labor. Add the overhead to this amount, usually $\frac{1}{3}$ of the cost of labor, and then add the profit, even if this is going to be small. Be sure that there is a profit showing, and added to the other two items. Go down the line for a typical operation in each department of the shop and you won't have any trouble in showing a profit. Our set of books show the income and expense for each department in the garage, such as tire, oil, general repairing, body work, welding, sale of accessories, etc.

The mechanic doing a welding job or repair job in the shop is required to keep an account of the time spent on a job, also the materials used. The gauges on the acetylene outfit are used to determine the amount of gas used. We figure the unit price for the gas at a price high enough to take in the average time spent on the job. We find that job tickets are especially valuable because they supply so much information and make our records more complete. Also they are very useful in planning for the future.

We use the portable arc outfit on the hour basis. We know from past records of time and materials used, how much it costs us an hour to run the outfit, usually $1.50 an hour. The time cannot always be figured accurately in advance, so we keep a record of the time spent on each job, also a record of the materials used. We charge $1.00 per K. W. of electricity used by the high-line machine. This charge includes welding rods and time usually. In our books the amount we have spent for material is all charged to the department of the shop using this material. The welding supplies are charged to the welding department. Labor on a welding job, and the amount of money collected from a welding job are credited to the welding department. In this system a minutes' scrutiny of the books will give you the profit each department makes for the shop. The smaller jobs, fifty to a dollar, are marked with a chalk. When the job is called for and the amount collected, the mechanic doing the job is credited with the amount and the department is credited with the same amount later.

Good equipment and good men in the shop are necessary for the customer's satisfaction. But good parts are equally important. Genuine

parts, the best you can obtain, should always be used. The same thing is true in the selection of supplies for the shop, such as welding rods for the arc machine, shellac, grease, and oil. The best material you can buy is the cheapest.

After a mechanic has learned to weld he should visit other shops and see how they handle their welding problems. He can always pick up new ideas that he can use, no matter how well informed he is. He should spend a few days each year attending the various welding clinics and demonstrations, sponsored by the manufacturers and jobbers of welding equipment. These shows are held all over the country, and it is an easy matter to attend the closest ones. The mechanic has an opportunity to see the latest in equipment, and the newest and best way to do a particular job. He will acquire enough enthusiasm about his work to last him until he attends the next clinic.

We make it a point to attend all these clinics, welding and carburetor, demonstrations and shows, that are held within 500 miles of our city. We rarely miss one.

We make it a hard and fast rule in this shop to do all the jobs, that come into the shop, as soon as possible. They are finished as quickly as we can do them. Take care of today's business and you won't have to worry about the future business. When a customer wants parts ordered, we make it a point to get the order out, either by mail or telephone, before he leaves the shop. We try to keep our catalogs and specification sheets handy and up-to-date. We can give the customer real help this way, in the ordering of parts, even obsolete ones. This is another way to advertise and get customer contact. We estimate that one-fourth of our business is the result of personal contact and solicitation.

Speaking of contact, the arc machine makes more contact with potential customers than any other item of equipment in the shop. The minute the arc is struck, you have a group of men talking about it, what it can do, and what it has done for some of them. No matter how many mechanics may be busy in the shop, the arc is the thing the customer will notice and comment on. They can see the arc, it is a novel sight to most customers; therefore it is easier to sell its use than other shop equipment.

Good Repair Shops Should Have Arc Welder.—Another reason why the arc welder should be in the good automotive repair shop is that the mechanic who is also a good welder, draws more trade than the mechanic who does not weld. The welding mechanic finds opportunities to employ time-saving methods in his every day repair work, and in this way can accomplish more during a working day than the man who cannot weld.

I have heard mechanics argue that all automotive shops cannot have electric welders, because there is not enough work for them. I think that when the saturation point is reached, and electric welders are as common as the acetylene torch in the repair shop, the welding machine will be as valuable as it is now in every day repair work, and as a time saver in other routine operations. The only difference will be that all automotive shops cannot hope to go to neighboring territory for welding jobs.

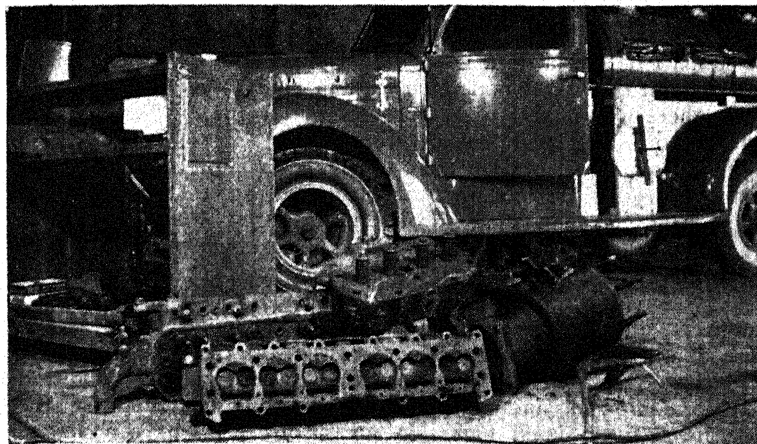


Fig. 10. One day's accumulation of money-paying jobs.

If I were buying an arc machine today I would not care if there were no blocks or jobs outside the shop, for there are other ways to use the arc to make it pay. A frozen block in a garage is like hair tonic in a barber shop! Both are accessories to the main business! The fact that there are any number of profitable block and head jobs every month in the year makes the buying of an arc welder all the more desirable. Fig. 10 shows one day's collection of money-paying block repair jobs.

Ability to observe is of great importance in getting extra business. Next to this, one should cultivate a knack of remembering the things he observes every day; later he can use them to his advantage when the opportunity presents itself. This habit of observing and remembering pays big dividends.

One-Stop Service.—The average customer likes to do all his business in one place, if possible. This is the reason for the small town merchant selling everything from crackers to cars and radios. There is just as much demand for this type of automotive shop, in fact, there is more demand for this type of shop today, than there was a few years ago. The more things the average customer can have done in the one shop the better he likes the shop.

It is good business planning, I think, to make an effort to keep improving the shop, to make it more useful to the community, by the installation of a good arc welding machine. Do this in just the same way you would add car washing or tune-up facilities. The cost of modern equipment to wash a car, or tune a motor, is about the same as the cost of a good arc welding machine, but the addition of any specialized equipment does not have the advantages, nor the usefulness of the arc machine. In the case of the former, the use is specific and specialized; it can be used in the shop for one specific job. The installation of the arc welder opens up a wide and almost unlimited field both inside and outside the shop. The use of the arc machine is general,

instead of specific, as in the case of buying specialized equipment for the shop. I have a modern wash rack, equipped with a power washer. It cost about the same as one of my arc machines. We use the arc ten times where we use the washer once. The returns from each in cold cash, is more lopsided in favor of the arc!

Then again, each service you add gives you more odds in favor of getting a larger share of the customer's service dollar. Obsolete methods and equipment in a garage cannot breed good service. You cannot handle many lubrication jobs on the newer cars with a grease gun and a creeper. You must install a hoist and power greasing equipment, or let your competitor do the work. Consider also the fact that all garages have to write off a certain amount of equipment each year because of obsolescence. Obsolescence is the loss of value due to the fact that designs are changing. New cars are designed; the same thing is true of equipment; and methods of repairing and maintenance change with them. Even simple items like grease dispensers have undergone radical changes and improvements in the last years. No one will deny that the changes have not increased their utility and value. Garages are glad to charge off the old fashioned grease dispensing equipment and purchase dispensers that are up to date. How long an item of equipment is going to have utility and value should be a major consideration when buying it. I bought a main bearing bar for a particular motor, and even though it paid for itself in a short time, it was soon obsolete. Four years after I bought it, it was of no value to the shop.

What a different outlook for the purchaser of the arc machine! A machine purchased 10 years ago is more valuable and useful now than it was then. The new user may be certain that the machine bought now will be more valuable to him ten years from now than it is today. Other equipment has less value as time goes on; the arc has more. Although the design of the arc machine may change, the older models perform as efficiently as when they were manufactured. There is practically no maintenance expense, and at the same time, new uses for the machine can be discovered everyday. Buying an arc machine is one of the most permanent investments, both for utility and for value, that the shop can make.

There is a chance for the automotive shop with an arc machine to be alone in the field of profit possibilities. Almost every kind of store in a community takes a share of the profits which originally belonged to the garage. Hardware stores, grocery stores, filling stations, lumber and elevator companies, and even drug stores sell this merchandise. There is nothing to be done about it now. It is true the garage does sell sparkplugs and oil, just as the hardware store; but it is also true that this garage will not make the money that it could without this kind of competition.

A shop having the arc, need have no fear of this competition. It is true you have competitive businesses like your own. They have to make a living too, and generally follow accepted automotive trade practices.

The shop with the arc machine as a nucleus, can build a profitable business. This shop will have something to advertise that is part of the shop. Instead of advertising "XYZ" spark plugs and oil, it can

be in the field alone telling the world about its arc machine. In other words the shop with the arc can feel more independent; begin to toot its own horn, and at the same time play a different tune on the cash register!

The key to success is understanding. An understanding of what the arc can do and is doing will enable a shop to immediately start making real money.

I can't imagine trying to run this garage without the arc, and at the same time I know that I have not discovered all its uses. Tomorrow will bring a new problem. I have every reason to believe that the arc welding machine will make the job more feasible and profitable.

I expect the arc to do as much or more for me in the future than it has in the past.

Chapter III—Commercial Weldery

By A. E. and M. W. (Mrs. A. E.) Gibson,
President and stockholder, respectively, The Wellman Engineering Co., Cleveland, Ohio. Complete paper contained 40,000 words, 70 photos.

Introduction.—In reviewing the progress made by the fabricating industries of America over a period of one hundred years or more, one is struck by the fundamental fact that no organization can survive unless it possess intelligent management, skilled workers and efficient tools for turning out its product.

Commercial welderies have too long disregarded these essentials; they have lacked the engineering knowledge required in welding technique, have known little of chemistry, metallurgy, heat treatment and design. Ignorance or neglect of these fundamentals has tremendously retarded the growth of welding, and consequently has retarded those advances in the design and fabrication of industrial machinery and structures which have in the last few years revolutionized all industry. To survive the keen competition which is the result of the general acceptance of welding, and of the widespread knowledge of welding design and technique, a weldery must have within its organization a knowledge of those sciences which are so intimately associated with both steel and non-ferrous metals.

Within the past few years great strides have been made in welded fabrication, chiefly because young engineers, pioneering in the field, have dared to discard old theories and to give unprejudiced and constructive thought to design.

In this presentation of a commercial weldery, the procedure in obtaining a contract for a welded lathe will be given. The work will then be carried through the engineering department and the shop. With this as a background, a concise description of organization, supervision of welding operators, equipment, management, design, and cost control required for successful operation will be presented. The methods employed to advertise and acquaint the trade with the facilities. engineering and welding skill of the company will be outlined. Also there will be shown the effectiveness of research and investigation as applied to the use of the newer low alloy, high strength steels, welded with alloyed electrodes, with the weldment suitably heat treated for tensile strength, ductility and resistance to fatigue and impact.

In this treatise on commercial welderies, the authors hope to outline, with bold strokes, the basis upon which success is built.

Contract for a Welded Lathe.—In answer to an inquiry as to whether we wished to quote on the fabrication of a welded lathe, we wrote the purchaser asking for the privilege of having an engineer call to discuss their requirements. The request was granted; our engineer called. With the aid of a book of photographs of actual weldments,

and a brief description of our engineering, fabricating and research facilities, the engineer convinced the customer of our ability to accomplish the work successfully, and was given their written inquiry and drawings.

ESTIMATE

CLIENT The - - - - - - - -Company

DESCRIPTION

Date 11/4/37
Proposal 6-24578-Rev.
Contract
Spec.
Drawing 12 Customer Dwgs.
Reference

Machines in Est. (1) Machines Reqd. (1)

	MATERIAL			LABOR & BURDEN				BURDEN		
	Weight	R	Value	Dept.	Hrs.	R	Value	R	Value	
Plates	11722	2.80	328.00	Structural	245	1.40	343.00			Inq. Date
Shapes	395	3.90	15.00	Welding	270	2.25	607.00			Source
Bars	5175	3.25	169.00	Forge	5	2.00	10.00			Str. Wts.
Rails				Machine	675	2.60	1755.00			Mech. Wts.
H. Beams				Floor	450	1.45	652.00			Str. Labor
				Pipe						Mech. Labor
				Electric						Summary
Sheets				Carpenter						Checked
Ch. Plates				Paint	25	1.20	30.00			Approved
Rivets				Ship						Ordered
O. R. Waste	530	3.00	16.00	Bend	60	2.00	120.00			Shipped
Total Str.	17822		528.00							
Cast Iron	1052	7.50	79.00	Total L & B	1730		3517.00			
Lin. Plates				Adm. 17½%			615.00			
Cast Steel	640	11.50	74.00	L B & A			4132.00			
Semi-Steel				Material			1076.00			
SAE 1112	92	4.00	4.00	% Mat.						
" 1020	395	3.50	14.00	1 Machine			5208.00			
Shop Forge	40	3.00	1.00	Machines						
O. S. Forge				Drawings	25	1.95	49.00			
				Patterns	85		137.00			
H. R. Steel	560	3.50	20.00	Adm. 17½%			35.00			
C.D.&T.P.St.CR	1			Patt. Mat 157 ft. @ 11¢			18.00			
Bronze										
Babbitt				Erection						
Pipe				Adm. %						
Bolts	10	7.50	1.00	Field Exp.						
				Tools, Jigs						
Total Mech.	2790		193.00	Adm. %						
Electric				Tool Mat.						
				Royalty						
O. S. Pur.	107		25.00	Comm.						
Stress Relieving				Dest. Frt.						
and Sand Blast.			300.00							
				Tax			57.00			
				Cost			5502.00			
				Profit			198.00			
				S. Price			5700.00			
Sundries										
Inc. Frt.			15.00							
Total O. P.	107		340.00							
Paint										
Ship Mat.			15.00							
Total Mat.	20719		1076.00							

Fig. 1. An estimate of material, labor and development cost is essential for intelligent pricing.

In the preparation of our estimate, we included in detail, (See Fig. 1), the weights and cost of the various materials required, the labor hours by departments carried out into labor and shop burden cost, the administration charge, and the engineering and pattern development cost. To the summary of all these items, called the "cost", was added the profit expected and an item called "tax", which is equal to 1% (for 1937) of the selling price to cover the social security tax. The selling price was thus obtained. A proposition stating the conditions upon which we would be pleased to accept their order, was sent to the customer. In due time an order for the work was received. The proper papers for the shop were written; materials not in stock were ordered, and production started.

Only that part of the cost estimate pertaining to the actual welding fabrication will be discussed here. To determine the material cost, the detail drawings were sent to the drafting room where draftsmen figured the gross weight of the metal required. The estimate, (Fig. 1), with the various metal weights listed, together with the drawings, was then given to the estimators who figured the labor. In estimating the labor, each piece was broken up into various operations such as layout and template labor, shearing, shaping on hydraulic presses or bending brakes, gas cutting, fitting for welding, welding, cleaning and chipping for appearance, painting, and shipping. In estimating the welding time, the actual feet of welding required was ascertained. Knowledge of the number of feet of welding per hour obtained with similar weldments was the basis used for arriving at the welding labor hours.

A data sheet, (See Fig. 2), was written, and given to the shop, purchasing department, and cost department. This sheet showed the material and labor listed in the estimate, and was used as a guide for purchases and shop control of labor.

In preparing plate for welding, it is shaped by shears or is gas cut. When using heavy plates, it is advisable to see that they fit closely, because if large gaps are left, the amount of filler metal necessary may be 50% more than is required if the parts fit closely. Therefore, with the head frame, a layout is made of the developed' plate, and the proper paper template provided for gas cutting.

The designer employed one of the most effective methods of cost reduction, not only to reduce welding labor, but to improve the appearance of the product; that is, the use of a bending brake or power press to bend metal, rather than welding two or more plates to obtain the desired shape. The head consists of as few plates as possible, the four vertical sides being one plate bent to shape, requiring but one vertical welded joint instead of four. The two bearings are of cast steel securely welded to the frame.

All detail parts were stress relieved after welding and before machining, and were also sand blasted for removal of scale. The completed lathe had all the welds ground, filled, and painted. This procedure was specified by the customer, who desired a product comparable in appearance to that of any modern machine tool.

[illegible]

DATA SHEET

C. O. 1453
PROP. 6-24578-Rev.
EST. DATE 11-4-37
DATA SHEET ISSUED 12-15-37

CLIENT The - - - - - - - - - - -Company

DESCRIPTION One 72" Welded Lathe

MATERIALS REQUIRED FOR One MACHINES

STRUCTURAL	WEIGHT	RATE	VALUE	LABOR HOURS
PLATES	11,722	2.80		Struct. 245
SHAPES	395	3.90		
BARS	5,175	3.25		Weld 270
RAILS				
H-BEAMS				Forge 5
SHEET STEEL				
FLOOR PLATE				Bend 60
RIVETS				
WASTE				
WHSE. ALLOWANCE	530	3.00		
TOTAL STRUCTURAL	17,822			
MECHANICAL				
IRON CASTINGS	1,052	7.50		Mach. 675
STEEL CASTINGS	640	11.50		Floor 450
SHOP FORGINGS	40	3.00		
OUTSIDE FORGINGS				Paint }
SAE 1112	92	4.00		Ship } 25
HOT ROLLED STEEL	560	3.50		
COLD ROLLED STEEL	1			
BRONZE CASTINGS				
BABBITT				
SAE 1020	395	3.50		
BOLTS AND NUTS	10	7.50		
PIPE				
STRUCTURAL ON MECH.				P & S Mat. $15.00
TOTAL MECHANICAL	2,790			
OUTSIDE PURCHASES				
Miscellaneous	107		25.00	
Stress Relieve & Sand Blast			300.00	
LOCAL FREIGHT			15.00	
DESTINATION FREIGHT TO FOB Our Works				
DRAWING 25 HRS.				
PATTERNS 83 HRS. 157 ft.				
PATTERNS LUMBER				

Fig. 2. A data sheet, carrying the detailed information on weight and cost of materials, and estimated labor hours, should guide in purchasing and production.

In Fig. 3 is shown a copy of the estimate and actual cost summary of the work. The welding labor overran the estimate by twenty hours, due to the insistence of our inspection department that larger fillet welds be made than were originally estimated. The total labor is fairly close to and within the estimate. However, a substantial saving in the cost of the labor-burden item was made, due to a total labor saving of 128 hours and because the actual labor and burden rate, during the period the work was fabricated, averaged \$1.90 per hour instead of the estimated \$2.03 per hour. The reduction of \$80.00 in administration was the result of the lower actual hours; an administrative charge of 17½% of the labor and burden was used in the estimate and in the cost sheet. It will be noted that the estimate of the structural and mechanical material is within approximately 3% of the actual. A saving in the cost of thermal stress relieving and sand blasting resulted from the lower prices obtained at the time of placing this work. A profit of more than 17% was realized on the order.

Management.—The success of every weldery is built on the interest, belief in welding, and encouragement of some one executive with authority to act. Regardless of the knowledge of the subject, and the enthusiasm for it among subordinates, little progress can be made unless an executive in the organization is keen for welding. The co-ordination of engineering and fabrication, the necessary expenditures for equipment and supplies, the ceaseless drive for efficiency in design and production, can only result from executive support. The lack of these essentials spells failure, or at best, produces but mediocre success.

Granting that it is convinced of the advantages of welded construction, the management should at once take steps to train some promising individual in the organization for the work, or failing that, they should employ a competent welding supervisor. The latter procedure is preferred from the standpoint of obtaining quick results. A competent welding supervisor must be more than a good welding operator. He must have the ability to handle men, and must realize that results are obtained by leadership and not by the use of a whip. He must be firm in his insistence that a worker give a dollar's service for a dollar in pay. He should have a knowledge of welding costs, of strength of materials, of metallurgy, of metallography, of machining operations. He should have the knack of devising short-cuts and inexpensive appliances to facilitate work, and should think in terms of the dollar. He should keep in close touch with the actual hours of welding and know, as the work progresses, how the actual time compares with the estimate. He should be alert in scrutinizing the appearance of welds to disclose defects; and should bring to the attention of the engineer suggested changes in design in order to better the product or to reduce the cost.

Operator Qualification and Training.—Operators are obtained in two ways: by training inexperienced applicants, and by hiring men who have had previous experience in other plants. In the former case, preference is given to a high school graduate who has had some machine tool experience. Our beginners start with a minimum wage

of fifty cents an hour. We do not operate an apprentice course as such, but beginners are given close personal supervision. For the first day, the new man is given a hand shield and told to observe the work of an experienced operator. He is then given a welding machine, electrodes, and sufficient scrap steel. After being instructed as to the operation of a welding machine, he is allowed to weld under the direction of the welding supervisor. Our training is all done on 400 ampere D. C. machines, using heavily coated electrodes. As the beginner acquires some skill, he is given simple, unimportant details to weld. He is required to check the quality of his work by making frequent nick-break tests. It is only when he can butt weld two ½″ plates, each Veed to 30°, without objectionable inclusions, gas pockets or lack of penetration, and produce true fillet welds in both flat and vertical positions which shall have the required tensile and ductility properties of filler metal, that he is permitted to perform our more important welding operations. The time needed to acquire sufficient skill is from four to six months. Highly stressed low carbon steel weldments and the low alloy, high strength steels are not entrusted to him until he has had several years experience.

When a rush of work requires the employment of experienced welders, we advertise by personally passing the information of our requirements through our employees or through the newspapers. When a welder applies, we ask him if he is willing to make a qualifying butt weld test. The nick-break test is made in the presence of the applicant, and if the work is of such nature that our supervisor feels that with a little practice the applicant can perform the test successfully, he is allowed further tests.

This method of qualifying an operator has been questioned many times with the statement that a nick-break test does not measure either tensile strength or ductility. We have found, through years of experience with tensile, bend, fatigue, impact, hardness tests, and metallographic investigations, that the nick-break test is by far the most difficult one to pass. We know that sound welds with proper grain structure will have the tensile strength equal to that of low carbon steel and the ductility requirements of the generally encountered codes. Our judgment of an operator's ability from a nick-break test has not failed in over five years' use, and too, this type of test can be made at practically no cost to the company, and of but one or two hours of the applicant's unemployed time.

Some of our operators have been qualified by the National Weld Test Bureau for welding unfired pressure vessels with plate thickness from ⅝″ to 1½″. These welders have built a large number of pressure vessels under the supervision of insurance companies.

Our hours of work are 44 per week with overtime after 8 hours per day and for Saturday afternoon. All our welders belong to our own employees' union with which we are on the most friendly terms. A vacation with pay is given every employee who has worked for us one year.

Equipment.—In view of the developments constantly being made in welding equipment, we believe five years is the extent of time a weld-

COMPARISON OF ESTIMATE WITH COST

Client Order No. T-3537-A [redacted] Order No. 00 1453

Proposal No. 6-24578-Rev. CLIENT The - - - - - - - - - - Company 37

Specification ________ DESCRIPTION One (1) 72" ______ Lathe

Drawing ________ By ______ ESTIMATE IS FOR (1) MACHINES—(1) MACHINES REQUIRED F. O. B. Contractor's Works

STRUCTURAL AND MECHANICAL MATERIAL

	Estimate Weight	Estimate R	Estimate Value	Cost Weight	Cost R	Cost Value
Plates	11722		328.00	13176	2.54	335.03
Sheets						
Floor Pl.						
Shapes	395		15.00	391	2.48	9.70
Rails						
Bars	5175		169.00	5196	3.40	176.86
Rivets						
O.R.Waste	550		16.00			
9" Sq.Billet				324	1.83	5.93
TOTAL STRUCT. MAT.	17822		528.00	19086	2.76	527.52
Iron Cstgs.	1062		79.00	1065	7.19	76.56
Steel Cstgs.	640		74.00	637	10.30	65.61
SAE 1112	92		4.00			
Shop Forgings	40		1.00	367	1.83	6.72
Out Forgings						
Hot Rld. Stl.	561		20.00			
Cold Rld. Stl.				352	5.19	18.27
SAE 1020	595		14.00			
Bronze						
Babbitt						
Pipe & Fittgs.						.02
Bolts	18		1.00	32	.10	3.21
TOTAL MECH. MAT.	2790		195.00	2468	6.95	170.38
Misc.O.S. Purchases	107		25.00			30.25
Stress Rel.) Sand Blast)			300.00			147.70
Sundries						.86
Local Frt.			15.00			1.90
TOTAL OUTSIDE PUR.	107		340.00			180.71
Paint)						8.05
Ship Mat.)			15.00			3.01
TOTAL ALL MATERIAL	20719		1076.00			889.67

	Estimate Hours	Estimate R	Estimate Labor	Estimate Burden	Cost Hours	Cost R	Cost Labor	Cost Burden
Structural	245		345.00		260¾	.89	232.44	138.26
" Prem.								
Welding	270		607.00		289¾	.91	264.09	289.73
Forge & Bend	65		130.00		70¼	.83	58.01	75.26
Machine	675		1755.00		694	.95	654.41	940.12
" Prem.								
Layout								
Assembly	460		652.00		264	.80	212.40	158.37
Pipe Fitting								
Electrician								
Carpenter								
Shipping)	25		30.00		9¾	.76	7.44	5.31
Painting)					19¼	.66	12.72	7.73
Error Time								
Total	1730		3517.00		1608		1441.61	1614.77
Total L. & B.							3056.28	
Adm. 17½ %			615.00				534.85	
Total L. B. A.			4132.00				3591.13	
Total Material			1076.00				889.67	
% on Mat.								
Total			5208.00				4480.80	
Dwgs.	25		49.00		13	1.49	19.37	
Patterns	83		137.00		76⅔	1.41	108.41	
Adm. 17½ %			33.00				22.36	
Patt. Mat.	157		18.00		104'	10.00	10.40	
Erection								
Adm. %								
Field Expense							12.04	
Tools & Jigs								
Royalty								
Commission								
Dest. Frt.								
R. & A. 1 %			57.00				57.00	
Total Cost			5502.00				4710.38	
Profit			198.00				989.62	
Selling Price			5700.00				5700.00	

REMARKS

Misc. O.S.P.

Grease Fittgs.	.94
Brake Lining	6.67
Cap Screws	22.64
	30.25

Summary By

Date

Base

Checked By

Date

Approved By

Date

REMARKS

Date Shipped

Checked By

Date

Fig. 3. After completion of a job, a comparison of estimate and cost is made.

ing machine should be used. Not that the equipment is worn out in that period—we know of many welding machines which have been in continuous operation for 10 or 12 years—but that the developments perfected make it advisable to adopt this program. All our welding machines are depreciated over a period of five years and in turning them in on new equipment, no book loss is sustained. Both D. C. and A. C. welders are used. The D. C. machines are portable; the A. C. are both fixed and portable. Proper instruments for registering voltage and amperage are attached to each machine. Adequate head shields for protecting the operators are essential. Electrode holders capable of insulating the heat from the welder's hand are a necessity. We have provided all the portable welding machines with protecting frames and steel lifting hooks so they may be safely carried by an overhead crane to locations not accessible by transportation on their own wheels

It is our experience that D. C. welding machines are so sturdily built that little or no upkeep is necessary over the period they are kept in service in our shop. They are, however, periodically inspected by our electrical service men.

While we know that welds made with bare wire are satisfactory in many fabrications not subjected to high stress, we have ruled out such wire solely because of the possibility of it being used in structures where shock and high stresses will be encountered. The electrode cost is so small a part of the overall cost of welding that the added ductility secured by using heavily coated electrodes justifies the small extra expense. We carry in stock a wide range of electrodes from $\frac{5}{32}''$ to $\frac{5}{16}''$. Several types of electrodes, the so-called "fast" rod, alloyed electrodes, as well as those more suitable for vertical, overhead and A. C. welding are stocked. In addition to low carbon, heavily coated electrodes, we have on hand rods for welding cast iron, stainless steel, and brass, also several varieties of hard facing electrodes which are quite extensively used on equipment subject to severe abrasion. For instance, we hard face hundreds of bucket lips and teeth, as well as rams for open hearth charging machines, and other details which would otherwise have too short a life in service. The type of electrode to be used is specified on our drawings or is selected by the welding supervisor.

To facilitate welding, we provide a number of large heavy cast iron tables having suitable bolt slots for set-up work and for clamping work preparatory to tacking. A number of lighter section tables are also available, which can be readily moved. These are used as supporting structures for jigs and fixtures. Tables are an indispensable facility for a properly constituted weldery. We also have several cast iron floor plates set in concrete, which are used for setting up large structures. These plates provide flat and level spaces approximately 20′ x 30′ in area and are located in several sections of the welding shop. The tables and floor plates are all cross lined to aid in setting and checking work.

In the preparation of steel for welding, shears, and power or friction saws are required. Heavy sections unsuited for mechanical cutting are shaped with a gas torch. Even with light sections a torch is necessary where contours vary from a straight line. In addition to the required number of hand torches, it is desirable to have one or more

mechanically operated gas cutting machines. The fixed type with pantograph motion and the two directional travel carriage type are equally serviceable. In addition, at least one portable gas cutting machine to operate on a portable rail for straight line cutting, or on a radius arm for circle cutting, is of great service.

A number of methods of contour control are used in mechanical gas cutting. Magnetic control and metal templates are convenient and efficient with large production, but both of these methods are expensive. On small lot work paper templates may be used, or the outline may be drawn on a sheet of steel to be used as a guide for the tracing wheel. Each of these latter two procedures is satisfactory and economical, and we use them commonly in our shop.

When a large number of gas cut parts is to be made, multiple cut-

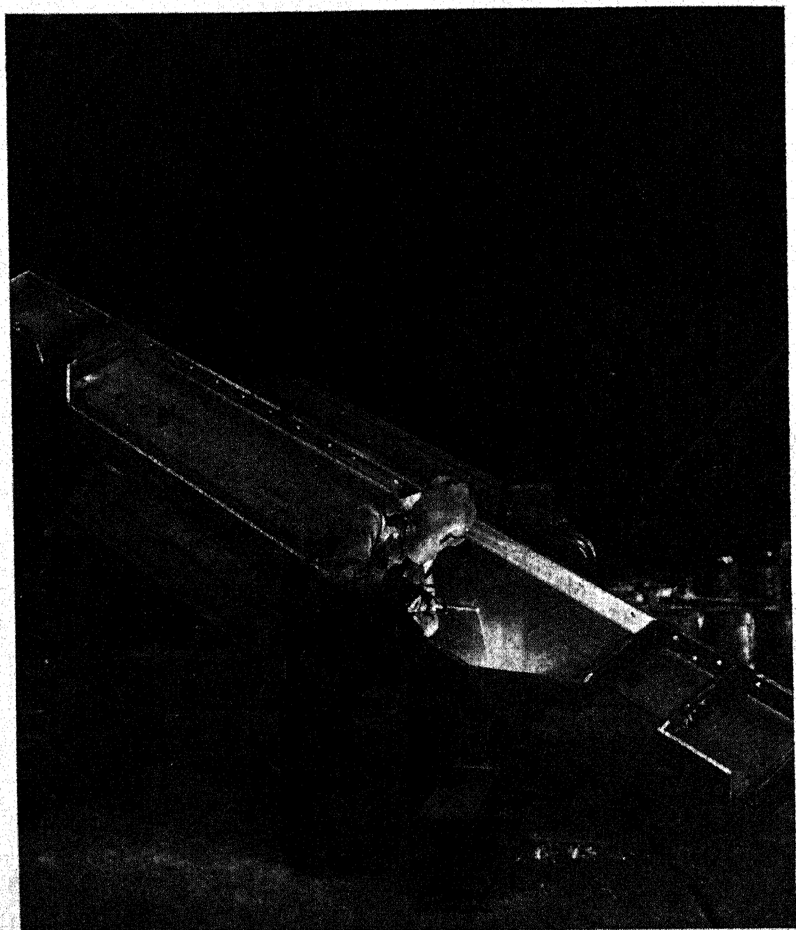


Fig. 4. No successful weldery can afford not to have suitable equipment for positioning work for welding.

ting torches can profitably be used on mechanically operated machines, thus materially reducing the labor cost per piece.

Today, no properly constituted weldery can afford to be without positioning machines. While equipment of this kind can be bought, most welderies prefer to design and construct their own machines as suited to their particular requirements. The larger machines, for large and heavy work, should be power operated. The smaller sizes may be hand operated. Fig. 4 illustrates a large type positioning machine

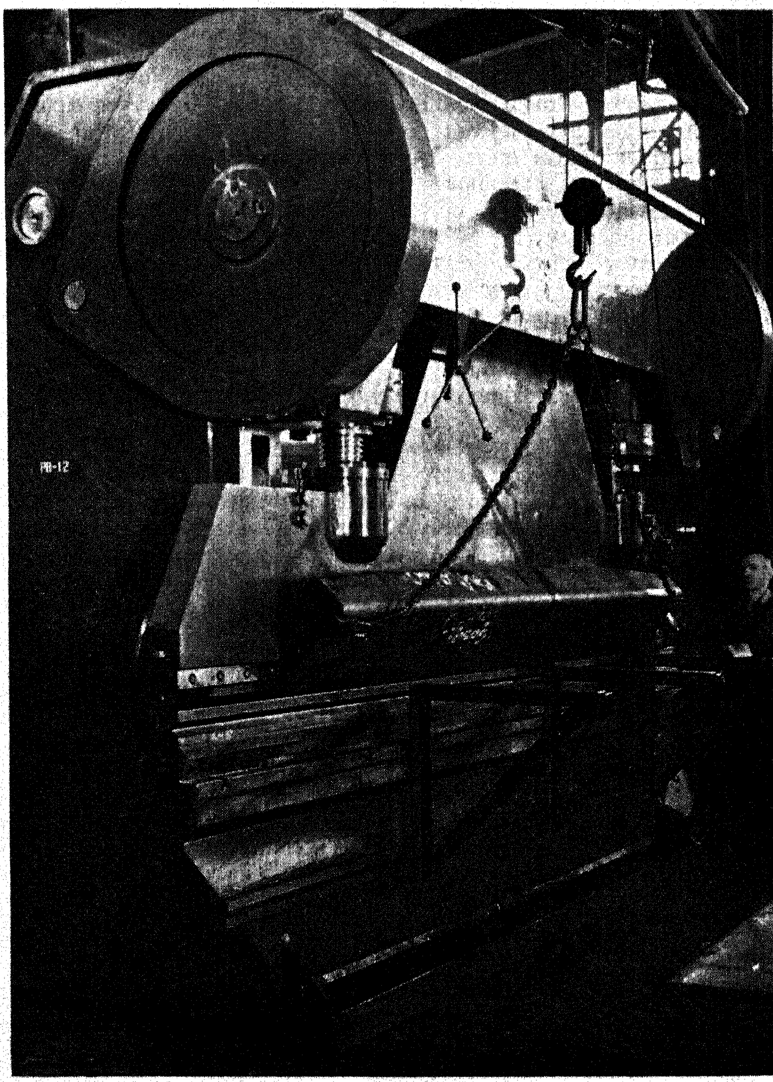


Fig. 5. There is no more profit producing-tool in a weldery than a plate brake. Note that brake is all-welded.

designed and built in the author's plant. The power operated machines should be equipped with remote push button control to enable the welder to operate them without having to move from his welding position.

A structure, once fastened to a positioning machine, can be quickly revolved into proper position for welding, thus eliminating the delays incident to desired setting with the use of a crane. In addition, "fast" electrodes can be used without danger of undercutting, and symmetrical fillets can be obtained. Savings in welding time of from 10% to 30% are regularly effected, and overhead cranes—no shop has enough of them in busy periods—are released for other work.

The shaping of cylindrical and conical structures is usually performed on power driven bending rolls. We have, however, found a bending brake more advantageous for conical work, if the cone is composed of two or more longitudinal plates.

Our bending rolls are not heavy enough for some of the work we produce, and often it is necessary to have plates rolled in plants hundreds of miles away.

The extent to which proper tools for bending metal eliminate welding labor, is too little appreciated. Fig 5 shows a brake with a capacity of 13′—6″ of ½″ plate (10′—6″ between housings), bending a ½″ x 11′—2¼″ plate into a channel shape. Two strokes of this press eliminate 22½ ft. of ½″ butt weld, which would be required if the design called for the welding of the detail with three plates. The saving in time and labor cost is obvious. Note that the brake is a completely welded structure.

Another type of power tool for bending material of heavier sections than can be handled on plate brakes is the hydraulic press. Not only is this tool useful on heavy work, but also on plate of lighter sections when bent edgewise. A press of this nature is better than a plate brake for bending large and heavy plates, because the application of power in three directions eliminates much of the shifting of the material by hand that is necessary with a brake.

Too much stress cannot be placed upon the necessity for keeping down cost in welding. If welderies are to retain the fabrications which have found their way into their shops, it will be only through intelligent design and by reducing the labor to a minimum, always the chief item of cost. We know of no more effective tool for accomplishing this than power machines which can shape metal quickly and inexpensively, often cutting out as much as 75% of the welding time.

Unfortunately, in most welderies there is too little realization of the importance of welding fixtures as aids in reducing labor. In many instances fitting time is 75% to 100% of the required welding hours. Much thought and study should be given to the design of suitable fixtures for aligning metal to be welded, both from the standpoint of interchangeability of parts, and of reduction of cost.

Fixtures should be of sturdy construction so as to prevent distortion due to localized welding heats, and should provide means for quickly setting and clamping the various parts of the structure. Fig. 6 shows a striking example of an efficiently designed fixture. This fixture is designed so that it not only holds the various parts rigidly, but the lugs

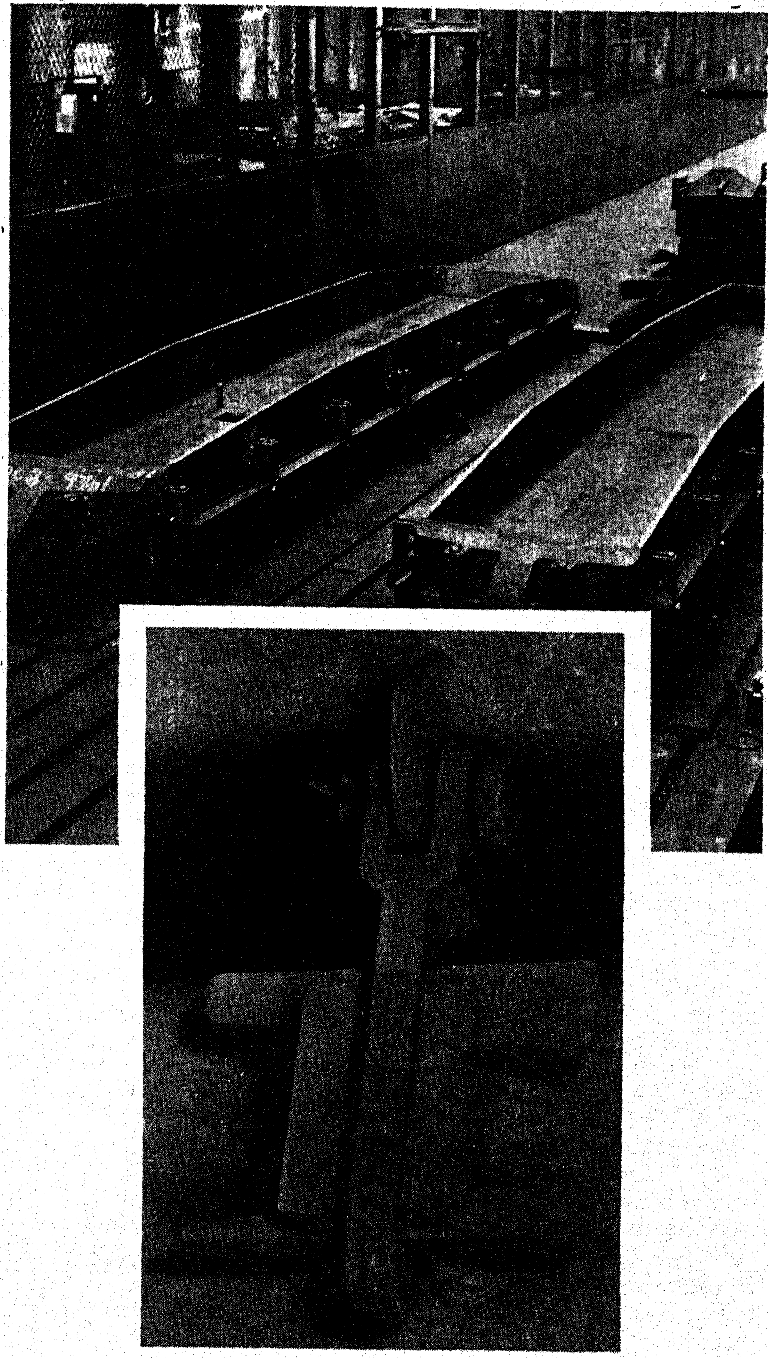


Fig. 6. Fixtures are indispensable. These two align 43 separate pieces Note spring steel snap ring to hold lugs.

are held with spring steel snap rings which can be applied in but a few seconds. To position all these parts properly without a suitable fixture, would be almost impossible. With it, the entire assembly of 43 separate parts is made in less than 10 minutes.

There are certain classifications of work which demand special facilities and equipment which are unnecessary in other lines. If the main product of a weldery is class one pressure vessels, facilities for thermal stress relief and heat treatment are essential. Every weldery has occasion to thermally stress relieve some portion of its products. Forty to fifty point carbon steel, gas cut before machining, needs to be annealed to reduce the hardness resulting from air hardening.

For heat treatment, a suitable furnace, either gas or oil fired, is needed. In almost all industrial localities, heat treating equipment is available as a commercial service to the trade, and if the quantity of work to be heat treated is not large, it may be best to depend upon other companies to do the work. We find that two oil fired furnaces, required for our forging and flanging work, are a great advantage to us in heat treating certain of our welded products. At times we have much larger pieces to stress relieve than our furnaces will accommodate, and we send this work to a commercial heat treating company or to one of the large steel foundries in our district. For best results, the furnace should be equipped with a thermostat to control the temperature.

With some large weldments, where grain refinement is desired, the heat treatment is done in pit annealers. The temperature is slowly raised to slightly beyond the critical point, and held there until the structure is uniformly heated throughout. The heat is then turned off, the annealer covers removed, and the temperature lowered as quickly as possible through the critical range. When a temperature of 1000° F. is reached, the covers are replaced, and the annealer is allowed to cool slowly. This procedure produces a modified normalized grain structure, and eliminates the possible distortion, and the objectionable cooling strains, which would result from a true normalization in removing the welded structure from the furnace at approximately 1600° F.

Investigation and research have become necessary functions of a successful weldery. Whether a shop employs one or one hundred welders, it is important to know the quality of an operator's work. To qualify a welder for code work, necessitates the use of a testing machine for determining the ultimate and yield points. The investment required to enable a weldery to do its own tensile testing would not be justified in a small shop, as testing laboratories are available whose charges are moderate. In large organizations, and particularly those where other tests are regularly called for, the cost of a tensile testing machine can be justified. We have a 200,000 pound capacity machine on which tensile and free bend tests are made.

When research work is carried on, and a research department is maintained, other equipment such as fatigue, impact, and hardness testing machines is used. Metallurgy has become so generally recognized as a science of importance to welding, that microscopes for study of grain structures have become a necessity.

For more than eight years we have had the active co-operation of a technical college in our city in carrying on extensive research in the welding of low alloy steels.

While machining facilities are not essential to a weldery, and many successful ones operate without machine tools, there is a great commercial advantage in being able not only to fabricate welded equipment, but to machine it. There are many instances in which a complicated structure may be handled best by building it in sections and machining certain parts before total assembly and complete welding. Details which require bosses made from rolled steel bars are generally much cheaper in finished cost when the bosses are cut off in lathes and rough bored in the same setting. In other cases, satisfactory results and lowered costs are made possible by doing the necessary machining before welding.

Since the average weldery has been developed as an addition to a previously organized metal fabricating company, a complete analysis of capital equipment will not be attempted. Also there are many successfully operated welderies which purchase steel cut to order, or carry stock sizes which are prepared for use by gas cutting. It is possible to carry on extensive welding operations without saws, shears, tables, floor plates, or other auxiliaries. The total capital investment is dependent upon the scope of work to be attempted and the capacity of the plant. The cost of the main items of equipment is as follows:

400 Amp. D. C. Welder	$ 610.00
500 Amp. A. C. Transformer Welder	590.00
300 Amp. A. C. Rotary Welder	615.00
600 Amp. A. C. Rotary Welder	720.00
½″ x 10′—6″ (between housing) Plate Brake	12,500.00
Pantograph Mechanical Gas Cutting Machine	1,750.00
Two Directional Travel Mechanical Gas Cutting Machine	750.00 to 3,200.00
Portable Gas Cutting Machine	125.00
Large Power Operated Positioning Machine	2,000.00 to 4,000.00
Small Hand Operated Positioning Machine	350.00 to 500.00
Hand Gas Cutting Torch	45.00

Engineering and Design.—In the organization of a commercial weldery, the next step is by far the most difficult, and upon it depends the success of welded fabrication; it is absolutely essential that competent designers and detailers be obtained. It is only through having the courage to depart from past experience and training that welded design can succeed. The writer has experienced instances in his company where attempts to redesign cast details for welding have failed nine times, but the tenth try resulted in a design highly successful, both from the standpoints of efficient operation and reduction in cost. The promises of revolutionary design in castings is remote, but with welding, the opportunities are unlimited. All that is needed to insure success is inspiration, imagination, creative thinking, and the will to pioneer.

In the development of equipment, our first concern is to create a design that will do the work efficiently. For example, let us take a wall type machine for loading coal into ships. It will consist of a sill mounted on trucks to operate on a horizontal rail supported by the structure of the pier, a second sill on trucks supported by a second rail on top of the pier, and horizontal thrust rollers to resist the outward pull on the top sill and inward push on the lower. A suitable frame must be provided, securely attached to the upper and lower sills for supporting the elevating boom upon which is located a movable hopper, and suspended thereto a telescopic chute for passage of the coal into the hold of the boat. A pan for guiding coal from the stationary pier bins to the movable hopper must also be provided. Many mechanical units for performing the various functions such as longitudinal travel, gate operation, pan elevation, telescopic chute swing, and trolley travel drive are required. We will present the development of but one unit, the boom-elevating mechanism.

Having determined the amount of wire rope necessary to raise the boom, the diameter and face of the drum are worked out on the basis of drum pitch diameter being forty times the rope diameter. After estimating the weight of the pan, and deciding upon a reasonable operating time cycle, the necessary horsepower and gearing are figured. A sketch is then drawn showing the component parts of the mechanism. Necessarily it must be supported on a suitable base of sufficient rigidity to resist the stress of operation; the gearing should be enclosed in oil tight housings. The designer has considerable latitude in the selection of fabricating methods and choice of materials. In older days cast iron would have been his choice because of its availability and low pound cost. With the advent of stronger materials, cast iron was widely superseded by cast steel, which gave better insurance against failure in service. Today we have a third type of construction—welding, which offers the possibility of greater strength and lower weight, and can be built much more cheaply than by the older methods. Our designer, therefore, chooses this type of construction. The sketch shown in Fig. 7 is the result of the designer's study.

If the proposal develops into a contract, the sketch becomes the design from which the detail drawings are made. This is the point at which careful calculations are made for operating efficiency, strength, and low cost production. Generally, estimates of various methods of construction are studied. Consultation with the shop fabrication management is held. When the details have been drawn and have received the approval of the superintendent of the drawing room, the executive in charge of design and production looks over the details. Suggestions for improvement of operation or cost of production are made, and the detail, after being rechecked for strength and clearances, is sent to the shop.

The frame is constructed of I beams, the sides having part of the beam webs removed by gas cutting, the flanges bent down and welded. This type of construction lends itself to low cost as the steel mill performs most of the required shaping. The welded drums having a shell of 1⅜" plate rolled to 55" diameter, two plate webs and rolled steel hubs. Drums of this size are considerably cheaper than steel

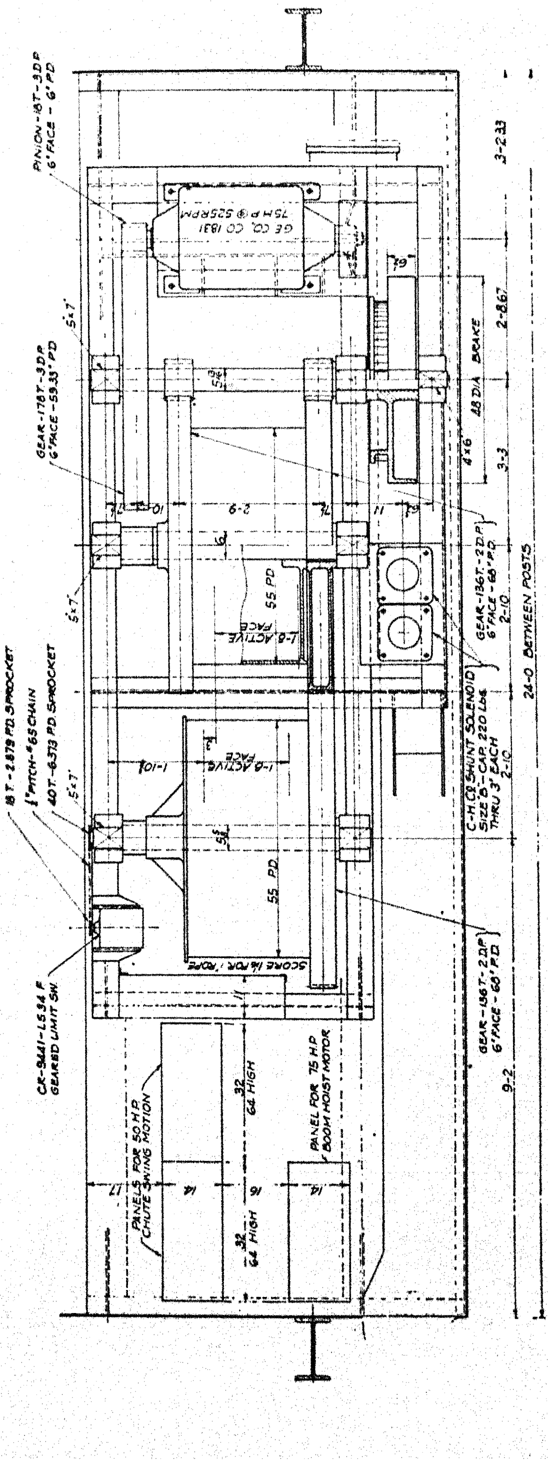


Fig. 7. The designer's study of a welded boom-hoist mechanism.

castings, the finished weight being materially less in welding, and not to be overlooked, the machining cost is about 25% less than is necessary with castings. This saving is due to the fact that much less finish is required in welded construction, and the metal is free from sand, hard spots and the defects which cause interruptions in machining by stopping work to repair them.

Our cost analysis of the two methods of fabrication of a 48" pitch diameter by 42" face drum, at today's market, is as follows:

Steel Casting, 5,000 lbs. @ 7¾c lb.		$387.50*
Welded, 5,150 lbs.**		
Shell 2750 lbs, including cost of rolling	$ 93.00	
Other Material 2000 lbs. @ $2.60 H.	52.00	
C. S. Hubs 400 lbs. @ 10c	40.00	
Structural Labor 16 Hrs. @ $1.45 Hr.	23.20	
Welding 50 Hrs. @ $2.25 Hr.	112.50	
Total Welded Cost		$320.70

*Pattern cost not considered.
**Including scrap metal.

The saving of the welded design over the cast design is 17% plus the absorption of 66 hours of shop burden which would be lost if a casting were used. There is a further large saving in machining.

Previous mention has been made of the use of a plate brake and power press to shape metal to reduce welding. This subject is of such vital importance to design and low cost fabrication that too much stress cannot be placed on it. This is shown by data on an extractor head frame. The structure consists of a box section with four bends in a ½" plate, 56½" wide x 12'-6¼" long. The forming was done on a plate brake in four stages as shown in Fig. 8. The bend in the bottom side was made to provide space for the ram in forming the two lower side corners. In the last operation the bottom was flattened. The bending eliminates 50 ft. of ½" butt weld over that required if the frame had been constructed of five separate plates welded together. The cost of producing one of these in lots of four, exclusive of machining, is as follows:

Material	2,365 lbs.			$ 58.73
(Fabricated weight 2,025 lbs.)				
Layout, Shearing, Fitting	19.54 Hrs.	@	$1.45	28.34
Gas Cutting and Welding	39.76 Hrs.	@	2.25	89.46
Bending	3.63 Hrs.	@	2.10	7.62
Bending Brake	6.07 Hrs.	@	2.25	13.66
				$197.81

Our estimate of the necessary pattern to make the piece as a casting is $285.00, and a casting would probably weigh 25% more than the welded frame. Even if the weight were not greater, the steel foundry schedule

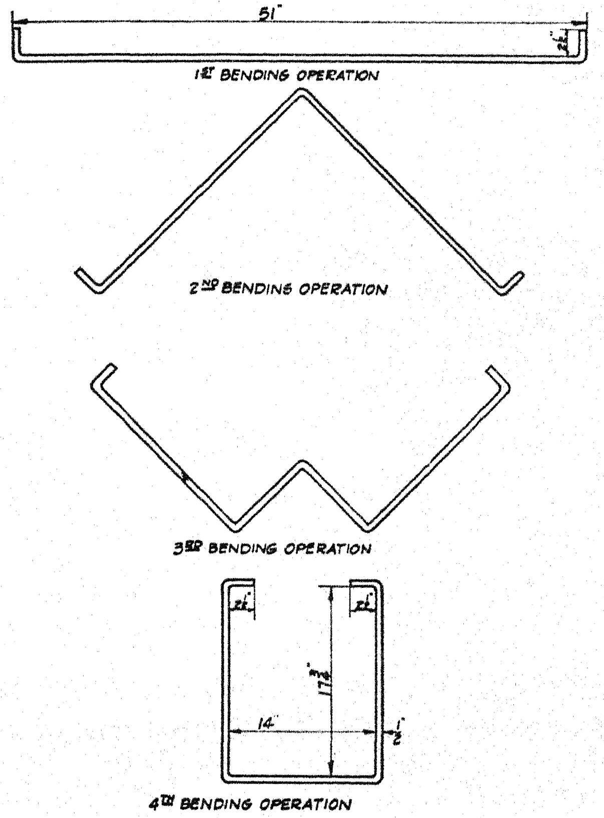


Fig. 8. Four steps in forming a box section.

of 8.6 cents per pound would make the casting cost $174.15. The total cast cost, including one-fourth of the pattern development, would be $240.40, or 21% more than the cost of the welded unit.

A group of four photographs of welded parts incorporating bent plates is shown in Fig. 9. One detail, the small bracket, at upper right, is interesting as a striking example of the part a brake or press can play in lowering cost. The cast iron bracket had been used for many years. It is a sheave support for the operating mechanism of a reversing valve. One day the author, in passing by one of these castings, noticed its heavy sections. Pointing out the casting, he asked the welding supervisor to see what could be done with this detail in welded con-

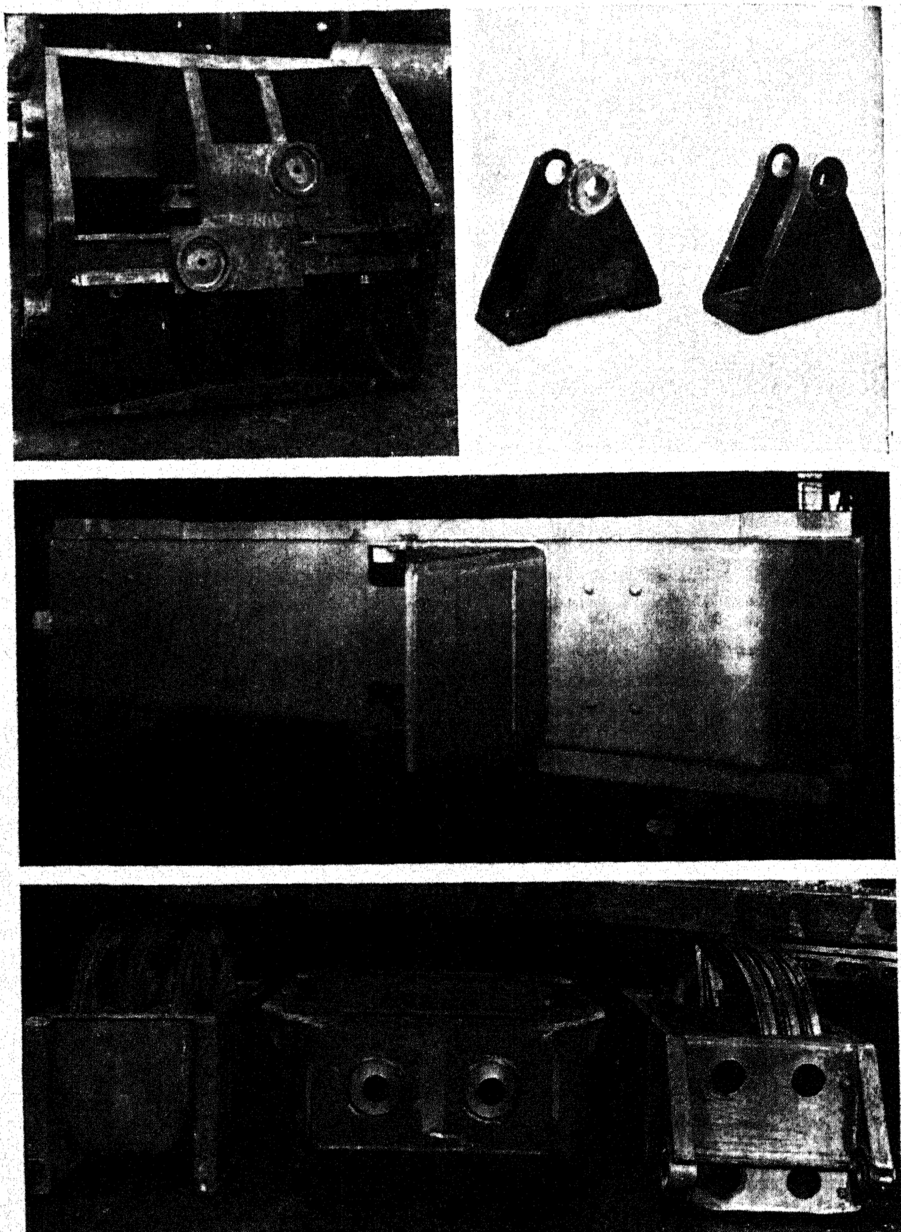


Fig. 8. Group illustrating wide application of power tools to bend steel.

struction. Sixteen brackets were made of welded plate. The per piece cost comparison of the two types is as follows:

Cast, 37 lbs. C. I. @ 7.16c lb.		$2.65
Welded: Structural labor 15 min. @ $1.45	$ .36	
Welding 7 min. @ $2.25	.26	
Bending 9 min. @ $2.00	.30	
Material	.85	
Total Welded Cost		$1.77
Saving in shop cost		$ .88
% Saving		33.2%

This saving does not consider the cost of the pattern or the expense of storing it.

Many engineering companies overlook the large savings made possible by changing over small mechanical details from castings to welded construction. Too often these details are given scant consideration because of the small amount of money involved in each item, and attention is centered almost entirely on larger pieces. During the course of a year we produce thousands of small miscellaneous details in welding, and the cumulative saving is surprisingly large. The tendency is simply to use the cast design drawing and change the construction to welding. This is almost always a mistake from a cost standpoint. Thought must be given to labor reduction through the use of rolled sections, and to straight line construction, which permit low cost in the preparation of the material for welding and of still greater importance, elimination of welding labor.

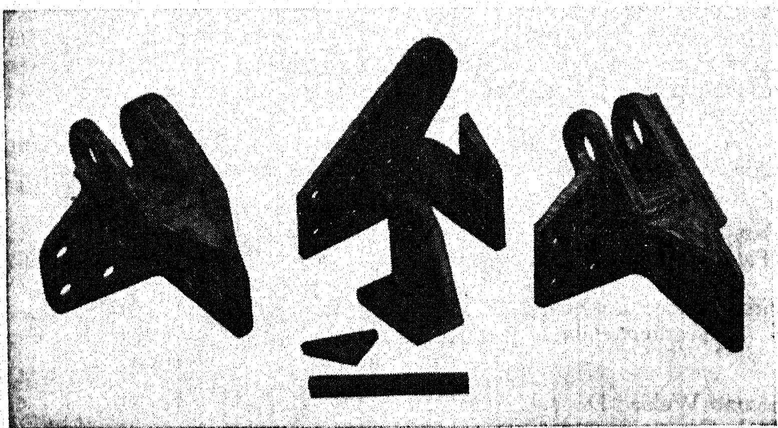


Fig. 10. Casting and components in welding.

Fig. 10 shows a cast and a welded corner bracket produced in lots of 50 or more at a time. Without considering the cost of the pattern, the saving of the welded part over the cast design is 21%. This saving

resulted from the use of a rolled angle and a plate with punched holes, which was bent to the required shape. The welding was thus reduced to a minimum and was done with the parts assembled in a fixture. The comparative shop costs of the cast and welded brackets are as follows:

Steel Casting 41 lbs.			$5.95*
Welded:			
Shear	3.5 min.	$.084	
Punch	1.4 min.	.034	
Bend	4.0 min.	.133	
Fitting	8.9 min.	.214	
Gas Cut	11.0 min.)		
Weld	62.2 min.)	2.745	
Grind	7.4 min.	.178	
		3.388	
Material		1.320	
Total Welded Cost			$4.71
Saving in favor of welded design			$1.24
% Saving			21%

*Pattern cost not considered.

In fabricating plants thousands of such parts can be found which lend themselves to welding with equally startling savings. Only lack of inspiration and thought on design prevents their transformation into the more economical welded construction.

The evolution of the counterweight sheave block shown in Fig. 11 is an interesting story in design. The one at the top of the photograph is a steel casting. It was originally made of cast iron, but high stresses and rough usage soon ended its career in that material. Our vigilance to cut cost corners sent the detail back to the engineering department for redesign in welding. The block in the center of the picture was the result, although there was no saving effected except the absorption of shop burden.

A more recent attempt at cost reduction, instigated by the welding shop, brought forth the detail shown at the bottom. The comparison of cost is enlightening.

	Lbs.		
Cast Steel (Pattern development not included)	1260		$89.05
First Welded Design	530	$72.36	
C. I. Counterweight	425	19.00	
	955	$91.36	
Second Welded Design	525	$55.59	
C. I. Counterweight	350	17.40	
	875	$72.99	

An additional saving in the latest design is the elimination of the facing of the four bosses in machining.

As so often happens, once one becomes thoroughly welding-minded, one intuitively looks at details with a cost appraising eye. Comparing

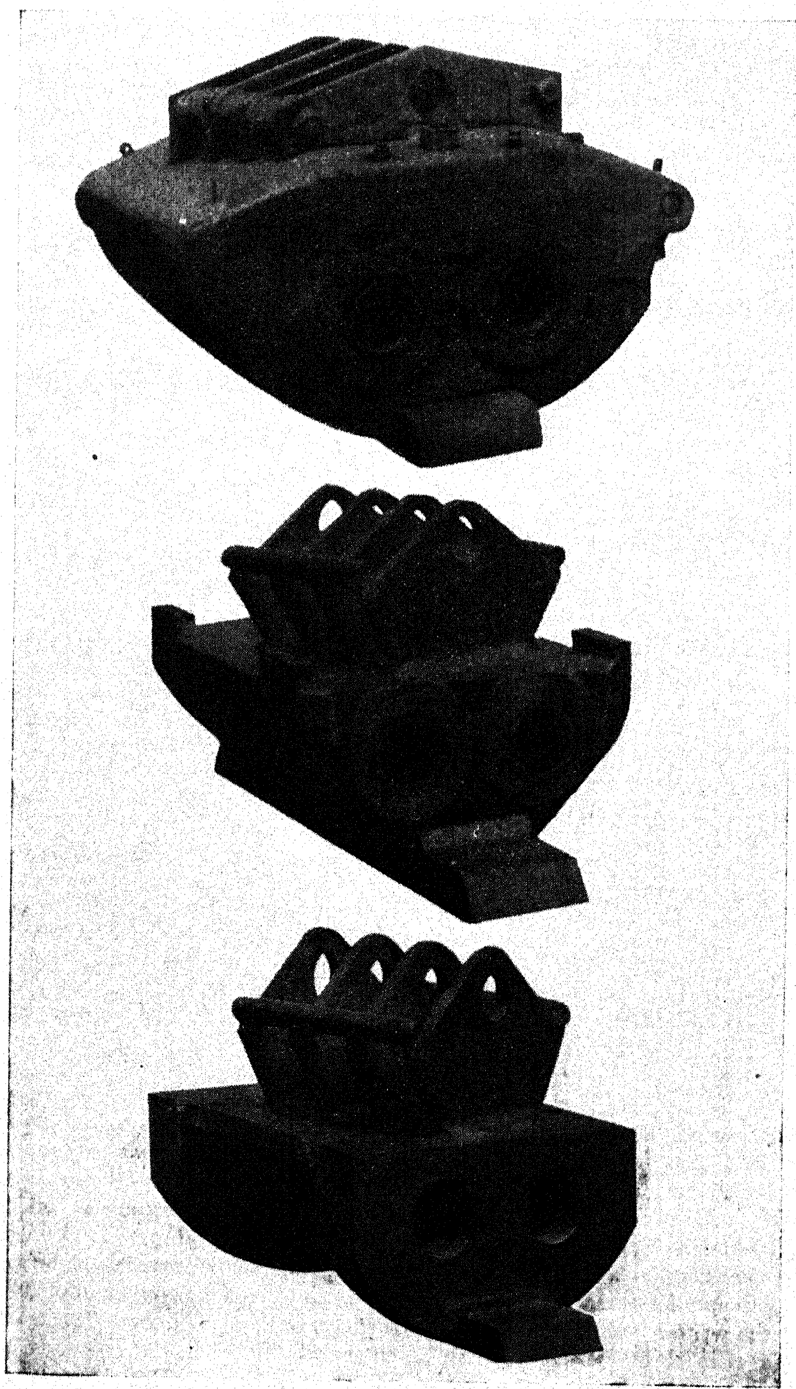


Fig. 11. Evolution of sheave block. Top—cast iron; center—cast steel; bottom—arc welded steel.

the two welded units, it will be seen that the bosses around the bored holes have been eliminated. This reduces the welding by six feet, and does away with the cost of the washers. The profile of the ends has been changed, simplifying the gas cutting, and reducing the material cost. In place of two heavy side plates in the first welded block, a light gauge bent plate has been used to provide the oil pocket for the shafts—a further saving both in weight and labor.

One of the functions of an engineering department is to specify exactly the size and shape of every weld to be made. It is not the duty of a welding foreman or operator to guess the stress to be applied to any weldment. Therefore, a suitable method of designating welds should be adopted and used on every drawing sent to the shop for fabrication. Our company has adopted the American Welding Society's standard welding symbols. Copies of these are given to every draftsman and to the shop. Guess-work is eliminated, and each weld is made in accordance with the calculated weld strengths determined by our engineers.

Research and Investigation.—With the advent of the new low alloy, high strength steels and their advantages of high tensile strength, high elastic ratio, and resistance to abrasion or corrosion, the problems of design and welding fabrication became complex. These new materials gave promise of solving the problems we had encountered with both cast designs and welded low carbon steel.

For years we had been disheartened by the costly failures of certain castings in clam shell buckets when these were subjected to severe tensile, bending and impact stresses. The constant increase of metal sections where failures occurred did not eliminate the breakage. The designs were such that in the castings planes of heavy metal were joined at right angles to lighter sections with heavy fillets at the angle. All the hazards of foundry practice were encountered in making these castings. The use of large dry sand cores prevented natural shrinkage of the cooling metal. Cracks developed in cooling. Shrinkage occurred, causing cavities which were hidden by the outer crust of metal. Segregations produced sections far weaker than the analysis of the heat would indicate. The result was failure in service, complaint from the customer, expense of replacement, and, of far more serious import to a manufacturer, a "black eye," making future sales to the customer extremely difficult. Fig. 12 shows a typical casting failure.

We were welders, we had a creditable array of imposing low carbon weldments to point to, and now we could obtain a new steel possessing 60,000 p.s.i. yield, 90,000 p.s.i. ultimate strength and over 20% elongation in eight inches. If we could redesign the faulty parts, build them by welding, using this steel, we felt certain the breakage would be overcome. However, we knew something about the effect of high manganese in steel. Here was an analysis containing 1.25%. We were familiar with the effect of chromium. Our knowledge of metallurgy prompted caution. Our investigation extended over many months, and the written results covered scores of pages, but out of it there developed a clam shell bucket which in seven months handled 125,000 tons of

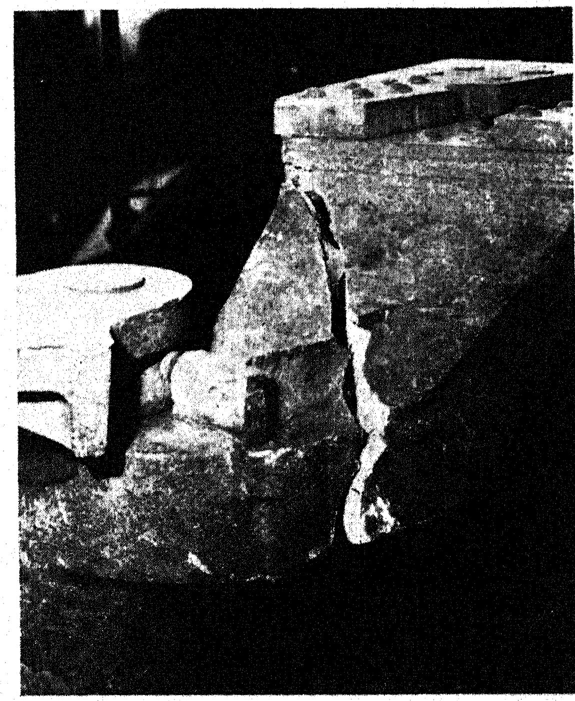


Fig. 12. Type of casting failure which forced clam shell power arm brackets into arc welded low-alloy steel.

rock in dismantling breakwalls at two Ohio lake ports. At the end of the working season a new coat of paint would have made the bucket look unused. The story of its performance traveled the whole length of the Great Lakes and the eastern seaboard. In the following two years we built and sold practically every heavy-duty dredging bucket purchased.

Our experience was so encouraging that we carried on an investigation of all the new alloy steels as they were brought out. As we became familiar with the technique of shaping, welding and heat treating of low alloy steels, and as our engineers, striving to increase the strength of equipment and reduce its weight, learned the short cuts in fabrication cost, a wide and varied array of structures became an inviting field for welded high strength steel. We have found those abrasive resistant and corrosive resistant steels a boon for equipment requiring these properties, and have used a large tonnage of it in iron ore and coal handling equipment and in services where corrosion is a problem.

It is interesting to note that we are now engaged in changing the design of our entire line of clam shell buckets, from 3/8 cubic yard capacity, and up, to welded construction. This development, on which we have been working for three years, has been slow and discouraging, due to the fact that the castings which we wished to replace by welding were light in weight and low in piece price, and the cost of forming

and welding the steel plate was high. At least ten attempts at design resulted only in failure from a cost standpoint. Finally, we have evolved a design which incorporates the bending of hot steel on a plate brake to eliminate much welding, have constructed heavy welding fixtures mounted on positioning machines, and are machining the metal before welding. This makes possible an overall cost comparable with that of the castings. We believe our new smaller buckets of welded design, sold with an absolute guarantee against breakage, will be the "mouse trap" resulting in the proverbial "beaten path to our door."

A striking example of the advantage of the use of low alloy steels is found in a recent proposal to an eastern railroad desiring coal loading equipment. The customer advised us that although our design was acceptable, the weight of three machines, built of low carbon steel, was too great to permit their use on the existing pier which had been designed to carry lighter equipment. Our knowledge of the use of high strength steels, coupled with welded mechanical equipment, permitted a design incorporating a chromium-phosphorus-copper steel in heavy rolled sections, resulting in a weight reduction of 20%. We received the order.

Cost Records.—The business wrecks strewing the road of America's industrial progress are more the fault of lack of knowledge of costs than any other single cause. Among medium and small sized industries, the greater number still adhere to an antiquated method of estimating costs, by lumping all operations into one price group, and by keeping actual cost records, if they are kept at all, in the same manner. For instance, all labor, layout, shearing, gas cutting, bending, fitting-up, welding, cleaning and machining carry the same labor and burden rate. The fallacy of this procedure should be evident to anyone who gives any consideration to the actual expense connected with these various operations. A layer-out, a fitter, a cleaner, work without the aid of power operated tools. Bending, gas cutting, welding, and machining operations are performed with equipment costing from a few hundred to many thousands of dollars. Some operations call for operators, who because of their high degree of skill, command high rates.

Other operations can be performed by unskilled or semi-skilled men. Depreciation of equipment, taxes, floor space, power consumption, lubrication, small tools, supplies, and many other incidental costs must be paid for. These go to make up legitimate charges which should be borne by the particular operation requiring them. To prorate these costs over all operations means that certain operations are sold at too low a cost, others too high.

As an example, we purchased last year a plate bending brake, costing $8,500.00. Dies and special equipment for it cost an additional $600.00. An electrically operated jib crane, at a cost of $500.00, was installed to service this tool. Valuable floor space, 20 ft. x 20 ft., was taken up, and the electric power to operate a 25 H.P. motor is consumed. Our estimate of the actual cost of operating this tool, the labor and shop burden, is $2.00 per hour.

Now, let us take another classification of labor, the fitting of parts for welding. No machine tools are required, with the exception of an

FORM A 3.19

BURDEN STATEMENT

DEPARTMENT D 11 Welding and Structural Shop PERIOD Nov. 1937

	EXPENSE ITEM	THIS MONTH	LAST MONTH	YEAR TO DATE
	Indirect Pay Roll Expense			
1	Supervisory Direction	765.00	765.00	7846.96
4	Clerical Workers	222.00	224.00	2362.65
6	Inspectors			
7	Crane Men	1430.07	1385.97	10132.07
10	Indirect Labor	922.53	822.10	7755.17
	Gen. Maint. and Repair Expense			
11	Maintenance of Machinery and Equipment	189.81	213.91	2162.57
12	Aux. Jigs, Fixt. Dies, Patterns, Spec. Tools	1.82	57.54	634.81
18	Auxiliary Mech. Equipment not Classified	314.59	372.34	4097.26
19	Furniture and Fixtures			
21	Building Structures	34.08	53.96	446.09
25	Building Lighting Equipment	11.30		30.89
	Operating Supply Expense			
26	Small Tool Expense	203.01	241.39	991.84
31	Department Supplies	960.30	871.28	8705.78
36	Elec. Lamps, Fuses, Conduits	40.74	2.02	101.83
41	Coal, Coke, Charcoal	14.10	42.73	171.78
42	Fuel Oil	154.06	153.07	2024.52
43	Gas	11.72	14.75	150.82
44	Water	66.13	61.73	748.21
45	Oxy-Acetylene	402.82	675.39	5286.93
	Supervision Losses			
46	Defective Work Losses			.59
47	Idle Time Losses	20.66	3.42	1565.97
48	Excess Labor Charges	.51	1.36	11.60
50	Other Errors			
	Administrative Expense			
57	Traveling Expense			
58	Telephone and Telegraph			
61	Gen. Office Supplies			21.98
62	Printed Forms			165.36
70	Adm. Expense Items, Unclassified			128.75
	Welfare Expense			
71	Compensation Insurance & Soc. Security	600.63	576.71	5406.73
	Total Direct Charges	6365.06	6538.69	60984.16
	Prorated Expense			
91	Depreciation	726.91	726.91	7996.19
92	Taxes and Insurance	475.58	475.58	5231.38
93	Building Floor Space Rental (Heat)	57.28	17.89	2393.01
97	Power and Light	1267.48	1119.61	12116.23
99	General Factory Expense	1114.60	1077.38	9893.48
100	Grand Total Burden Expense	10006.91	9955.05	98584.45

		Actual Burden Rate	.876
Productive Hours	11424	Burden Rate Used	.743
Productive Labor Amount	$9516.48	Productive Labor Rate	.869
Production Premium	$ 304.09		
Burden Amount Used	$8490.15		

Fig. 13. Monthly burden sheet helps keep expense in line.

occasional heavy lift with a crane. The fitter works with a rule, a square, and a level, setting the component parts properly and clamping them together preparatory to tack welding. True, the fitter is a skilled mechanic, paid possibly ten cents an hour more than the brake operator, but he uses no costly equipment, little or no power, and much less floor space. Our analysis shows this operation costs in labor and burden \$1.35 per hour. The average labor and burden rate for the entire department may be \$1.60 per hour. Now, let us assume that we have to figure a particular job on which the bending and fitting operations take an equal amount of time, say two hours. Two hours bending and two hours fitting at \$1.60 per hour is \$6.40. The actual cost of these same hours is \$6.70. The administration charge of 17½% of the labor and burden rate is \$1.12 in one instance and \$1.17 in the other. The total cost is therefore \$7.52, using an average labor and burden, and \$7.87 using the true labor and burden, a difference of 35 cents, or an actual loss with the average burden of 4.6%. This would reduce by nearly 50% the profit normally figured, and in times of keen competition, would completely eliminate the profit. The seriousness of this situation is that the company actually believes the job is profitable, and it is only

C.O. 1453
Daily Hours

	Chipping			Elec. Weld			Acet Cut			Rolling			Straighten		
DATE	Clock No.	DATE	HRS.	Clock No.	DATE	HRS.	Clock No.	DATE	HRS.	Clock No.	DATE	HRS.	Clock No.	DATE	HRS.
	1566	1/8	.86	1587	1/4	1,58	1579	12/13	.38	1501	1/3	1,80	1449	1/8	1,66
	·	1/14	3.61	·	1/5	8,00	1584	·	1,02				·	1/10	.86
	·	1/15	1,02	1585	1/6	4,16	1586	12/15	1,85				·	1/12	.40
	·	1/17	2,05	1587	·	6,32	1592	12/16	.70				1470	·	.40
	·	1/19	8,00	1585	1/7	6,64	·	12/17	1,80				1449	1/29	2,48
	1456	1/20	5,24	1587	·	2,22	1579	1/4	1,80				1470	·	138
	1566	2/8	1,98	1585	1/11	2,38	·	1/7	1,98				1449	1/31	.68
	·	2/9	1,34	·	1/12	8,00	1592	·	.74				1470	·	.68
	·	2/10	2,70	·	1/13	7,40	1579	1/8	.60				1449	2/4	1,93
				1591	1/31	2,54	·	2/9	.66				1470	·	1,93
				1589	2/9	.66							1466	2/10	1 00
					2/10	.92							1470	·	1,70

Fig. 14. A daily labor record by operations.

when the profit and loss statement is made—and with many small companies this occurs only at the end of the fiscal year—that the management finds the supposed profits do not exist.

Furthermore, in periods of keen competition, the flat rate basis of estimating often results in loss of orders which would be obtained if correctly figured. Our company has established labor and burden rates covering all operations. The following table lists them:

Cost Records

LABOR AND BURDEN
JOBBING WORK RATES

TOOL RATES—MARCH 15, 1937

Miscellaneous	
Weld	2.25
Struc.	1.40
Forge	2.00
Brake	2.25
Tool	1.70
Floor	1.45
Pipe	1.70
Elec.	1.95
Carp.	1.50
Paint	1.20
Patt.	1.65
Drawing	1.95
L. O.	1.60
HX 300	3.10
100	2.80
Roll Grinder 30	1.95

Vertical Mills	
VB18	5.05
16	4.50
12	3.55
10	3.35
8	2.80
6	2.45
5	2.25
VTL5	2.55
4	2.00
3.5	1.90
3	1.80

Planers	
P10	4.05
8	3.70
7	3.50
+5	3.95
—5	3.10
4	2.70

Slab Mills	
SM4	2.60
3	2.70

Slotters	
VS24	2.60
18	2.25

Horizontal Mills	
HB6	3.35
PB5	3.65
TB5	2.30
3	1.85

Saws	
CS10	1.65
CS 8	1.50
CS 6	1.25
BS 4	1.20

Horizontal Drills	
HD7	2.55
3	1.85

Millers	
PM5	1.95
4	1.80
3	1.65
RM1	1.35

Lathes	
L60	3.10
48	2.60
42	2.45
36	2.15
30	2.10
24	1.90
18	1.70
16	1.50
14	1.50

Bolt Threader	
BT2	1.50

Turret Lathes	
TL34	2.25
24	2.00
3	1.95
2	1.70
4	1.80

Drills	
RD 7	2.15
6	1.95
5	1.80
4	1.70
3	1.45
18	1.55
12	1.25
DR30	1.30
27	1.25
18	1.15
MD20	2.25

Gear Planers	
GP14	2.25
DP56	......
GC72	1.20
48	1.15
45	1.05
36	.95

Shapers	
HS24	1.30
HS16	1.25
KS42	1.85
KS36	1.75

Once a month the accounting department tabulates an actual burden cost for each department. The expense is broken up into many classifications, and the burden sheet carries the comparison with the previous month and the total for the year to date. The works management has before it complete information on burden costs. If the cost of any one item for any one month is high, a comparison with costs for previous months quickly shows the reason, and steps for correction can be taken. Information on any particular detail of the burden is readily available to a shop department head. A typical burden sheet is shown in Fig. 13.

Little work is obtained today without firm quotations. Therefore, when an order is received, the estimate upon which the work was priced is available. When the work order is sent to the shop, a data sheet accompanies it, listing the material required and the labor hours originally estimated. (See Fig. 14). Without this information, particularly the labor estimate, the shop would work completely in the dark. Every foreman should have the labor estimate available and be held accountable for producing the work within the hours figured. Daily records of consumed hours should be kept and be available so that the shop management may know at all times by comparison of the consumed hours with the estimate, just how the work is progressing. Fig. 15 shows the cumulative labor record. Some such method of labor control is essential for efficient management. In our company the detail record-keeping is not duplicated in the shop and office. The cost accounting department is not concerned with keeping a record of the labor details entering into the costs. Only summaries are kept in the office for compiling total costs. If detailed information concerning any operation is desired, it may be obtained from the shop office. Our shop labor records are kept by one individual for the structural and welding shop, which normally employs about 100 men. The expense of record-keeping is small and unimportant in comparison with the results obtained by holding the shop management responsible for results.

Publicity and Sales Promotion.—Our employees who contact the trade are engineers. They are familiar with our production facilities and are firmly welding-minded. This has prompted them to suggest to customers that better, stronger, and cheaper details may be made by substituting welded parts for those designed as castings. In many instances these sales engineers either make free-hand sketches during their calls, or bring the customer's drawings to our drafting room for redesign in welding before submitting prices on the work.

In addition to the personal contacts of our sales engineers, we advertise widely in trade magazines, by letters, a twelve-page yearly calendar, and monthly blotters broadcast to the trade showing our achievements in engineering and production. We furnish copy and photographs of welded equipment for national advertising by steel companies, and to manufacturers of welding equipment and supplies.

Realizing the direct advantage to us in orders through the advancement of welding, we have presented illustrated lectures before engineering societies and technical schools from the Atlantic Ocean to the Mississippi River Valley, and from Toronto to New Orleans. In addition to these efforts to promote the science and art of welding, we have written and published in technical and trade journals, scores of articles on various phases of welding, including research, design, and fabrication. Most of the material presented represented original work done in the particular field. We hope that this has played some part in acquainting the engineer, the fabricator, and the purchaser with the advantages of welded construction. Our plant, as are those of most modern welderies, is open to our customers and to our competitors. We believe that whatever benefits the welding art, and speeds the day of its universal adoption, will benefit us.

Conclusion.—One cannot review the industrial progress of the past few years without realizing that no factor has contributed more to that progress than welding. Our national wealth has grown as our industrial developments have made possible lower costs and a wider distribution of commodities. American incentive, ingenuity, and ceaseless effort have in the past borne fruit. Mechanized farming, mechanized industry, mechanized distribution are the only means of creating greater wealth.

What part will welding play in this program? The answer to that question can be found by looking at the record of the recent past. Today, our unmatched distribution of automobiles is the envy of the world. Without welding, the modern automobile could not be made. Our distribution of household labor-saving appliances is unparalleled. Estimate the cost of an electric refrigerator built without the welding art. In transportation, the electric locomotive, the light weight diesel engine, the

C.O 1453
Cumulative

Estimate 245 Structural 270 Welding 5 Forge 60 Bend

Total Hours Structural DATE	HRS.	Total Hours Structural DATE	HRS	Total Hours Electric Welding DATE	HRS.	Total Hours Electric Welding DATE	HRS	Total Hours Bend DATE	HRS	DATE	DRG	HRS
12/2	4.84	1/3	168 19	12/7	70	1/12	252 93	12/21	1 64			
12/3	12 84	1/4	185 05	12/10	2.45	1/13	268 33	12/23	3 54			
12/4	16 40	1/6	186.55	12/11	3 17	1/14	276.33	12/28	8.56			
12/6	22 39	1/7	193 50	12/13	6.13	1/28	276.79	12/29	9 65			
12/7	24.87	1/8	201.50	12/15	7 98	1/31	279.33	12/30	15 77			
12/8	25 85	1/11	202 34	12/16	11 69	2/3	280 11	12/31	19.45			
12/9	48 49	1/12	210.34	12/17	18 39	2/7	281 25	1/3	22 41			
12/10	53 16	1/14	221 95	12/18	21 83	2/9	288.09	1/4	24 83			
12/11	54.70	1/15	225 95	12/20	27 38	2/10	289.01	1/6	29 57			
12/13	55 82	1/17	228 00	12/21	45 23	2/14	289 73	1/8	31.23			
12/14	57.20	1/19	236.00	12/22	61 89			1/10	32 95			
12/15	67.46	1/20	241.24	12/23	68 02			1/11	33.95			
12/16	82 38	1/21	249.24	12/24	84.43			1/12	34.75			
12/17	89.17	1/22	253 24	12/27	104 53			1/20	38.37			
12/18	90 65	2/2	254 24	12/28	123.36			1/28	41 61			
12/20	90.80	2/7	255.04	12/29	131.04			1/29	46.57			
12/21	99.14	2/8	257.62	12/20	135.21			1/31	47.93			
12/22	108.59	2/9	258.96	12/31	138.66			2/4	51.79			
12/23	116.99	2/10	261.66	1/3	139.00			2/10	54.49			
12/24	121.55			1/4	144.78							
12/27	129.55			1/5	161 44							
12/28	137.87			1/6	179.92							
12/29	139.37			1/7	200.88							
12/30	153 79			1/8	209.48							
12/31	158.39			1/10	219.08							
				1/11	236.93							

Fig. 15. Cumulative labor record.

high speed train, and the modern ship have been made possible through welding. Increasingly, our bulk handling machinery, our bridges, our machine tools, our buildings, and furniture, have been built with the electric arc. This progress has resulted only because through welding can this stronger, lighter, more efficient equipment be built at lower cost.

With this background, can any engineer, any industrialist, yes, even any layman, question the importance of the welding art in the material progress of our people? This is a challenge to the commercial weldery. Will it accept that challenge?

In this analysis of a commercial weldery, we have endeavored to point out the fundamental principles upon which success is built: management, design, production technique, and research. We have said much about reduction of cost through reduction of labor. That is the basis upon which progress is built and a basis which the builders of welding equipment and supplies endorse one hundred percent.

There is every promise of the commercial weldery contributing its full share toward future national prosperity.

Chapter IV—Organization, Equipment and Operation of a Plant Weldery

By H. Thomasson,

Welding engineer, Canadian Westinghouse Co., Ltd., Hamilton, Ont., Canada. Complete paper contained 90,000 words and numerous tables, charts, drawings, etc.

When and Why Arc Welding Is Used.—This paper proposes to deal with the organization of a welding department within a machinery manufacturing plant for the purpose of producing parts for such equipment as is regularly built and sold.

The specific business of the said company is the building of electrical apparatus of every conceivable type from household appliances to huge generators, transformers and switching equipment, all of which are built in all commercial sizes. Arc welding is used to produce parts for every type of apparatus, in order to obtain the many advantages its use makes possible.

Each of the two methods formerly used in machine part construction, casting and riveting, had one very desirable property. The former, at its best, produced a homogeneous structure, but in the case of iron castings was in a metal of relatively low tensile strength, having little resistance to impact or fatigue stresses, while steel castings present technical difficulties so great that soundness in complicated forms is seldom attained. If the advantages of the two processes could be combined in one method of construction and the resultant product sold at competitive prices, it would be an outstanding accomplishment. Arc welding does this, taking rolled steel in either plate or structural forms, joining the pieces together as they would be in a casting and fusing the various members into a structure of uniform physical properties by the use of high strength, ductile steel as a joint metal. The product can be sold for the same or somewhat lower price than that built by either of the older methods, leaving a greater margin of profit to, in turn, permit the manufacturer to provide improved service for his customers.

Such a case is the fabricated bedplate, shown in the photograph, Fig. 1 used to support a 20 horsepower induction motor. Its total weight is 58¼ pounds, while that of its cast predecessor is 102 pounds. The total material weight required by the fabricated design is 59½ pounds, resulting in a mere 1¼ pounds of scrap, all of which comes from bolt holes or slots. The cast design requires 58 man minutes of machine shop labor to face, mark, drill and tap, with 70 man minutes to set up the machines, while there is no machine shop work on the welded one and the total fabrication labor is 104 man minutes, with 114 minutes required on each order to set up machines. The adjustment screws on the cast unit have been replaced by a single standard bolt working through a standard nut arc welded to an angle, to which the pair of bolts visible in the lower slots of the steel unit have been

welded. The upper pair of bolts is likewise united by being welded to a strap. Ten ounces of $\frac{5}{16}''$ diameter welding electrodes are used on each bedplate.

The level surface of the steel plate makes facing unnecessary so that machining labor is non-existent. This forms a splendid example of the application of steel plate arc welded construction in a comparatively light field.

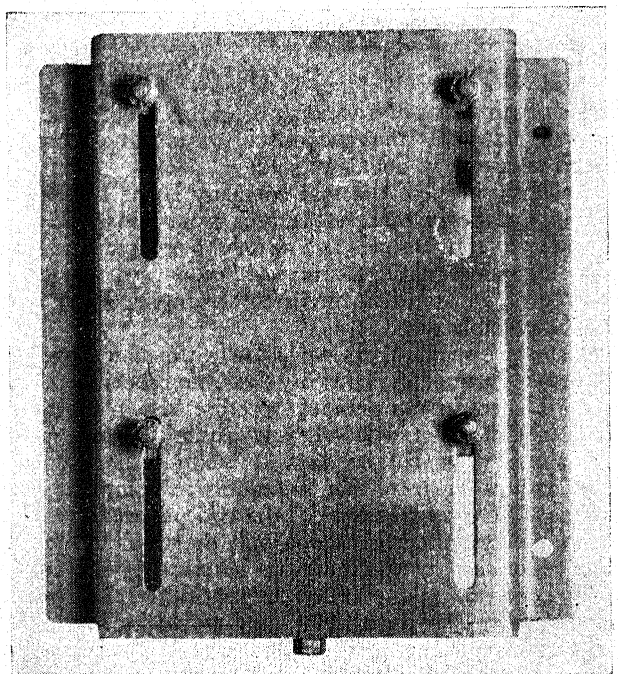


Fig. 1. Arc welded steel bedplate.

By applying arc welding, it has been possible to build into products greater reliability, capacity and structural strength. It has greatly aided and, in some cases, been responsible for improved designs, and for desirable but, heretofore, impractical refinements. It has brought about entirely new apparatus which contribute to the maintenance of uninterrupted electrical services that are essential to the welfare of every city and town and required by all industries.

From a manufacturing standpoint it has combined the good qualities of casting and riveting, the old methods. Thus, it makes possible structures with the physical properties and soundness of rolled steel with no sacrifice of joint strength. This, in turn, permits weight reductions, amounting in many cases to one-half or more of the former weight, with corresponding reductions in the cost of the parts. Arc welding has contributed to the health and comfort of those engaged in such work, by making it possible to have comparatively quiet, dust free

surroundings. Thus, the process has proved itself to be socially desirable and to be worthy of the confidence that society at large has reposed in it.

Designing for Arc Welding.—Modern electrical equipment can only be designed by close co-operation between the electrical and mechanical branches of the engineering profession. The multiplicity of form and function make it essential to have individuals in both divisions who are specialists in specific branches of the field. It can readily be seen that an engineer who is concentrating on radio or refrigeration would have little time to keep abreast of waterwheel generator or distribution transformer practices. Hence the engineering activities of the company with which the writer is connected have been divided into some twelve divisions.

Each division has in charge an engineer, who for years has specialized in the type of apparatus for which he is responsible. The divisional staff is composed of graduates in electrical engineering, who have passed through the shops as graduate students, followed by specialized shop work on the class of apparatus they are designing.

The mechanical engineering activities are located within and are a part of the draughting office, and are in turn divided into sections, each handling the work for its allied section of the electrical portion. Each of the eleven branches of the draughting office (the research section has no specially assigned draughting space) is headed by a mechanical engineer with many years' experience in his particular field, assisted by one or more graduate assistants, and as many senior and junior draughtsmen as the volume of business in that particular section makes necessary.

There must be, and is, the closest possible co-ordination between the two sections in order to get the most effective design. In some cases the desires of one are at variance with those of the other. Then very careful consideration is essential to obtain the best solution.

The regular engineering procedure followed when an order is received or a proposition requested, for apparatus which has not previously been built or designed, is to submit the order or request to the appropriate engineering division who make up the electrical design, passing it on to the mechanical section for completion. Usually there are limitations of location, size, shipping facilities, or other conditions under which the apparatus must function, that have an important bearing on the mechanical design. It is not unusual for customers to desire specific features incorporated into a design or even to request that a certain material be extensively used and to be willing to pay the premium for such extras; all of which must be taken care of in the mechanical design. This division controls the amount of or the extent to which a process such as arc welding will be used, specifies the materials of construction, the methods of joining the same and in general does all that the term "mechanical designing" implies.

The receipt of the electrical specifications by the mechanical engineering is a signal for a check to determine if a design exists that is suitable for the desired application. In most cases there is a tested and satisfactory design that merely needs application to the desired

unit. Then the problem is a routine one, solved by turning it over to a draughtsman with instructions to apply the specified design. Should such an applicable standard not exist, then the section head will go into the matter and determine by means of calculations and preliminary sketches the general features, including the type of construction, which parts will be arc welded, and which, if any, will be of cast steel or iron, with the chances in favour of arc welding since economy and fabricating convenience are the usual deciding factors. Not infrequently, parts are welded to avoid pattern, mould, core box and flask costs, which are a substantial item in limited production.

Thus, with the major factors determined, the job goes on the drawing board for the making of the assembly and detail drawings. Decisions covering the various points are made as they arise. Frequently the shop staffs are called in and use made of their knowledge as to the best solution from the manufacturing point of view. At other times the engineer has gone out to the plant with his problem and requested suggestions as to the best means of producing a given part with the equipment available, all of which results in co-operation and confidence between the designing and producing sections.

Standard lines are handled somewhat similarly to specials, except that the estimated activity made by the sales department has an important bearing on the methods of production and tool investment justified by the prospective business.

The methods and materials of construction are likewise affected by the estimated quantity; i.e., the designers would not think of specifying a cast iron frame for a large motor with a probable production of ten a year, nor would they be likely to use arc welded fabrication for the combined bearing bracket and end bell of a ¼ horsepower motor for household washing machines weighing less than two pounds each, with a fifty thousand per year production. Between these two extremes are innumerable cases in which the decision will hang on the plant's facilities, and the extent to which the organization is sold on arc welding, which in turn depends on the success that has attended earlier trials of arc welded jobs and on the ability of the welding division to produce the desired results.

Improvements in existing designs and changes in methods or materials of construction follow a less routine course, since the first step must be the birth of an idea for improvement, which may have as its object a better product, or lower costs—usually both. Development of the plan to the point at which it may be sold to the responsible parties can only be done by the originator, either singly or in company with others he has been able to interest. Since any person may be the parent of a worthwhile idea, it is not desirable to have red tape interfering with its development, but to have as free an intercourse between engineering and shop as possible. This attitude, combined with the welcome given to worthwhile suggestions, has provided the arc welding division with an unlimited scope to further the use of their process, resulting in a very desirable spirit of co-operation between the designing and producing sections.

In order that all divisions shall use the same basic forms and methods, the "Engineering Standard Sheets" have been developed,

covering every possible phase of engineering and draughting activity, with complete instructions necessary for uniformity of the drawings and information. They are the guide on all matters of procedure or routine and can only be changed with the approval of the chief engineer. Those which have a bearing on arc welded design include the calculation of working stresses, the design rules and stresses for welding, the methods for calculating weld stresses, the fusion welding symbols in use, the standards for welded joint design, the form and areas for butt welds, the strength of circular plates, the data pertaining to the concentrated radial loading of rings, finish allowance tables for flat and rolled steel plates and sheets, the formula for calculating bends in flat stocks and the method used to figure the size of material required to form a cone.

The draughting instructions and standard sheets cover data on making up a bill of material, showing what information should be supplied, the form to be used, how interchangeable parts are taken care of by group drawings and style numbers, how changes are made either in material or dimensions, and the methods of lining, lettering and shading.

The following rules should be taken into consideration when applying welds to any design:

1. Welding should be the minimum that is consistent with the stresses in all component parts such as the parent metal, bolts, and other fasteners, except in cases where leak-proof or minimum fillet requirements, appearance or machining stresses determine the amount of welding.
2. Specify size, type, dimensions, process specification, and location of all welds in accordance with the fusion welding symbols.
3. Specify water, oil, air or vacuum tight if required. Where it is difficult to describe this requirement by a single note, it is permissible to use the letter W, O, A, or V, respectively, with an arrow pointing to the section of the weld that is to be thus described, with an explanatory note on the drawing.
4. Welds should be easily accessible for manufacturing, repair, and testing with minimum handling and the position in which the welds are made should have the following order of preference: Flat, horizontal, vertical, overhead.
5. Machining allowances must take into consideration assembling, shrinkage in welding, distortion of parent metal, and variations in rolled sections.
6. Joints should be designed so as to minimize as far as practicable stresses due to shrinkage, secondary bending and eccentricity.
7. On composite joints (containing welds and rivets) the welds should be made to carry the entire load for which the connection is designed.
8. The size of fillet welds should be held to 3/8″ or less whenever possible. This facilitates making the welds in a single pass and results in reducing welding costs.

How Engineering Information Is Transmitted to the Shop.—The introducton of arc welding as a method of fabrication fitted into the

general system of plant operation and gave no reasons to change or modify it in any way. Hence, the writer can only outline the method used in this particular plant as one, but by no means the only practical way to transmit engineering and manufacturing information to the shop.

The one used in our works for this purpose has three major divisions, viz.: the Process Specification, the Order Information and the Drawings. Each is complementary to the other and forms a part of a standard system developed many years ago in continuous use throughout the plant since its inception.

The Process Specification forms a comprehensive detailed instruction for doing whatever class of work it is designed to cover. In each case it is made up by the engineer in charge of that work, and is carefully detailed to eliminate any ambiguous terms, and to be absolutely clear to any reader who is at all familiar with the work. In every case its scope is covered step by step, and on completion of the write up must be approved by both the chief engineer and the works manager before becoming effective. On being approved, copies are forwarded to all departments likely to need them and filed by the receivers under the process specification number for future reference.

Whenever an order is received for a machine, or part that is not regularly carried in stock, a stock order reading is issued and copies sent to every department that has work to do on it, including the engineering. This reading advises everyone concerned that such an order has been received and is to be proceeded with. This is officially known as a "Stock Order Reading" and gives a brief description of the machine, the number required, the customer, the shipping date and the type of information to be used in producing it.

In making the drawing, every piece of material, no matter how small, is given an item number and listed in the bill of material that is a part of the drawing, placed in the upper right hand corner of it. This bill of material gives the name of the item, the material from which it will be made, and lists all the dimensions of the material. The routing of the part is also given, with the first department listed drawing out the material, other listed departments doing their apportioned job and the last one listed assembling the various parts into the complete machine which is then turned into stock.

It frequently occurs in making up drawings that some needed part has been previously detailed on another drawing, in which case an item number is given to it on the new drawing but instead of specifying the material a reference is given to the drawing and item on which it is detailed. This facilitates the use of standard drawings for parts commonly required, greatly reducing the amount of detail that would otherwise be needed.

When the stores note that their stock of a given part is down to renewal levels, a stock order is issued for a quantity of such parts as the level of business indicates will be required during the next six months. Such a stock order merely calls for the required number of parts of style #———, and they are manufactured to permanent manufacturing information.

Any and all parts of machines that are carried in stock as standard parts are given a style number and manufactured in large quantities. The same procedure as for a special part or machine is used in that a stock order is issued to manufacture the required number of the desired style.

When a new drawing has been finally approved, an estimated required number of copies are printed and turned in to the Blue Print Depository, located at a convenient point in the plant. The using departments obtain these by means of a "Drawing Charge Card." The card is filled out with the date, the number of the desired drawing, the name, check number and department of the person needing the same, and presented to the blue print depository. They remove the drawing from their files and replace it with the charge card. Should it at any time be required, the cards indicate where each copy is.

When a change is made in a drawing, it is given a new sub number, i.e., all new drawings are sub No. 1, and on the first change become sub No. 2, and the change recorded marginally. New copies are sent to the Blue Print Depository, who at once take all cards for copies out of their drawing files, thus locating all copies. A messenger is sent around to exchange the new copies for the old ones. In this way no old drawing can remain in service. Obsolete copies are checked off the depository list and sent to the paper shredder for destruction.

The Organization and Supervision of the Welding Division.—The supervisory and office staff of the welding division takes care of three departments, namely, the arc welding section, a miscellaneous welding department using other forms of electric welding and brazing, and the forge and heat treating portion of the plant. The total number of employees at this date (April 1938) is 122, of which 70 are engaged in the arc welding section.

The shop office staff consists of: a welding engineer, a cost control man, a schedule man, an information clerk, a time keeper, and an office junior.

The supervisory staff on the shop floor consists of: a divisional foreman, assisted by a welding inspector and two mechanical inspectors. Taking care of material and shipments are: a combined receiver-storeman and a shipper.

Each person has clearly defined duties, those of the office staff being outlined in the following paragraphs, while those of the floor staff are given beginning on Page 770.

The welding engineer is responsible for the development of methods, procedures, and process specifications, involving or pertaining to arc welding or contributory operations. He must check all drawings and information to ensure an effective use of labor and material; assist the time study and cost departments in estimating and cost reduction work; test such new arc welding electrodes, auxiliary equipment or tools for contributory operations as seem worthy of detailed testing; assist the engineering and draughting office staffs in utilizing arc welding to obtain the utmost in economy and efficiency in design; supervise the training and selection of arc welders; assist the advertising and sales departments to tell the story of arc welded products, by the writ-

ing of articles and technical releases, and by the preparation and presentation of papers and talks on arc welding before various mechanical and engineering organizations.

The cost control man is a representative of the cost control division. He is permanently stationed in the shop office and is responsible for the establishment of the allowed time for every operation and piece of work done in any of the three departments forming the division.

In a plant, or a division of a plant that ordinarily has between 400 and 600 orders in progress at any given moment, for articles that range from a minute part of a radio set to huge frame or spider for a 50,000 H.P. generator, it is essential to have someone constantly at work checking material from stores and other departments, watching the orders to see that none get side tracked, and all are shipped by the required date, checking with other departments to determine such dates, and generally relieving the foreman of the multitudinous clerical details with which he would otherwise be burdened. Such is the work of the schedule man.

The information clerk is responsible for the writing out and the making of shop copies of all order information pertaining to the welding division, as outlined in that section, including the writing out and forwarding to the stores of the charge slips for plate or bar stock carried in the welding shop.

The use of an incentive system of wage payment increases the responsibilities of the time clerk, and although the group system of wage payment greatly reduces the amount of detail work, by reducing the number of job tickets to about 30% of those required by a good individual worker plan; it still further increases the amount of intelligence required by this position, since the group calculations are made by the clerk at the end of each pay period. The time clerk is charged with the writing out of all job tickets, and placing thereon, the allowed time as set by the time study man, noting the issuance of each card on the group information.

The junior or office boy's principal duties are to look after the blue prints, obtaining and returning the copies from and to the blue print depository. He is also responsible for the filing of all paper entering the office. Every piece of written matter received relates to either a stock order or to permanent manufacturing information, in which case it carries a style number. Everything that has a stock order number on it is filed under it, while data bearing a style number only goes into the permanent files. The filing and subsequent location if required is simple and easily handled by a junior.

Since such work is only attractive to a youth for a very short time, and the clerical openings cannot absorb many such persons, they are selected with the idea of their becoming mechanical apprentices.

The Arc Welding Shop and Its Equipment.—The equipment, required by a department organized to produce machine parts by arc welded fabrication, will vary to a large extent, depending on the type of product and the weight of material to be used.

Consideration is given to the fact that the parts must be prepared for assembly at a minimum cost, and the following machines are

recommended with this, and the need for accurate work to prevent loss of time in later stages, fully recognized.

A plate shear to take 3/4" thick plates in twelve foot widths; one portable mechanically driven oxy-acetylene cutting torch; one automatic template guided oxy-acetylene shape cutting machine; one combination strap, angle and channel shear and punch; one power saw for cutting sections up to 12" wide; one detail parts lay out bench; one set of horizontal angle rolls, capacity 5" x 5" x 3/4" angle; one 24" vertical drill for tapping and countersinking; one nibbler or shape cutting punch for 1/4" thick plate; one edge planer 20 foot travel, open ends; one set of plate bending rolls, 16 feet long; one, three to five punch, plate punching press, capacity 2 1/4" hole in 1/2" plate; one six-foot radial drill; one press type bender, 10 feet between housings, 1/2" plate; one three ram, sectional flanging press; one plate furnace to heat plates 6 feet square, equipped for the sectional heating of larger plates; storage for oxygen and acetylene drums; storage for templates for shape cutting machine; small plate bending rolls capacity 12" diameter cylinder, eight feet long, 3/8" plate.

The work of assembling and tack welding, or clamping the various components into form for welding, requires a large permanent floor plate to which the various parts may be clamped and a number of similar smaller plates for light weight products, installed at bench height for convenient working. Combined with these will be a generous supply of clamps, bolts, and dogs, while several machined angle plates, which may be clamped to either floor or bench plates to hold materials square with other parts held against the main plates, are highly desirable.

The actual welding equipment is required to serve at least 20 welders, and may be single operator motor-generator sets, or multiple operator constant potential generators, either of which supply direct current. Transformer sets using alternating current in commercial frequencies, or motor generator sets producing a special high frequency A.C., are available, and all types have advantages and objections. In addition to the welding current supply, at least four pairs of support rollers with adjustable roll centres are required for supporting tanks and other cylindrical parts for easy turning during welding.

Finishing operations consist of stress relieving, cleaning, testing, and primer coat painting. Provision is made for these in order that any form of product may be taken directly to the machining or assembly departments. They comprise a car bottom furnace in the lean-to portion with the car running out into the main bay for loading and unloading; a shot blast cleaning is similarly handled, except that the actual cleaning compartment is not located within the walls of the building but is outside and separate to prevent any dust escaping into the shop.

Test facilities provide for oil, air, and water testing to any desired pressure, with facilities for holding test pressures for any period. Very little water is used, except on destructive tests, while the test oil storage tanks are located under-ground and away from the building. A spray painting area is provided for, in order that all work may

be given a primer coat immediately after cleaning, thus ensuring the greatest possible freedom from surface troubles in service.

With the equipment outlined above the welding department is well equipped to handle any but class one pressure vessel work, and the addition of X-Ray facilities would make this possible. Much of that included is made necessary by the great variation in material and design that is an unavoidable part of the company's activity and results in a greater capital investment per worker than is ordinarily the case. In spite of this, the electrical industry has gone further than any other in the utilization of arc welding as a manufacturing process. It has done so for the single reason that it can produce better goods at lower cost with arc welding than with any other fabrication or casting process.

The shop floor layout, shown as sketch Fig. 2, is not exactly as it exists at present, but as the author would have it if such were possible.

The main aisle is 100 feet wide by 350 feet long, over which is installed three cranes, a ten ton that nominally works over the material preparation portion, and two twenty-five ton units to handle the assembly, welding and finishing work. A fifty ton lifting beam is used to couple the two larger ones together, and thus handle the occasional heavy job, with a total weight between twenty-five and fifty tons, without the expense of columns and craneways to carry a single unit capable of handling the heavier loads. A lean-to along one side 25 feet wide for 240 feet houses the office, tool and detail part stores, furnaces, die, fixture, and template storage, together with the electrical switchboard, wash rooms, and toilet facilities. Storage space for oxygen and acetylene cylinders is provided adjacent to the cutting machines.

The basic plan is the common one of material entering at one end, and being fabricated as it passes along the shop, with shipments going out from the finishing end.

The Shop Floor: Supervision, Inspection and Group System.—The foreman of the arc welding division is responsible for the quantity, quality, and delivery by the required date, of all work assigned to his sections. He selects the men for each phase of the work and controls the distribution of work to them. It is his duty to see that all his employees adhere to the plant rules and regulations, and that all equipment is operated in the safe and efficient manner that is conducive to high class work and low maintenance charges. He must see that all areas under his control are kept in a clean, orderly condition and must prevent waste or loss in any form. Safety, first of men, second of equipment, is his primary consideration at all times, as is the individual welfare of his workmen.

The welding inspector's duties are largely defined by his title in that he must inspect all welding during and after the performance of the work. This involves observing the arc welding as it progresses, to ensure that none of the ills of undercutting, voids, slag inclusions, or lack of fusion creep in, and that all work is of first class appearance.

He also does any training of new operators that are required and co-operates with the welding engineer in the development of improved technique, or in the testing of electrodes or equipment.

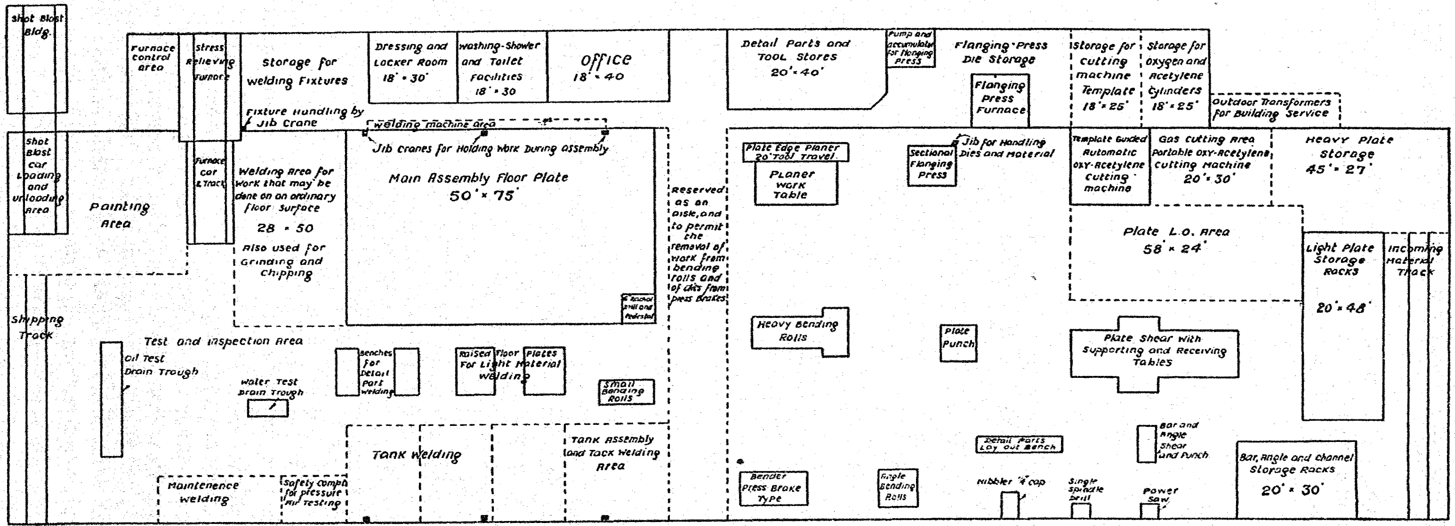


Fig. 2. Shop floor and equipment location. Scale $\frac{1}{8}$" = 1'

The two mechanical inspectors are responsible for inspection. It is their duty to check every job and to see that the work is in accord with the stock order information, and the drawing, and done to the process specification, if one is called for.

The duties of receiving material and parts from the plant stores department or other manufacturing sections, and of taking care of the same until required for use within the welding shop, are allotted to the combined position of receiver and storeman. He checks the incoming materials for quantity, signs the other department's copy of the shipping bill and mails it to them.

When an article is ready to be transferred either to the plant stores or to another department, the shipper issues the necessary credit slip or shipping bill, sees that it carries the inspector's acceptance stamp, and has one of the inter-departmental transfer trucks make the delivery, or in the case of large or heavy parts, has it loaded on a railroad flat car to be moved by the plant's switch engine.

A method of inspection has been developed that might be termed, "The Four Stage System," by which four inspections are made as the work progresses. In plate work, the first check is immediately after the lay out. In the case of sheared plate this point is after shearing and lay out but before punching, bending, rolling or other forming. In the case of irregularly shaped pieces for gas cutting, the lay out is checked before cutting but in the case of heavy plate (too heavy for shearing) being gas cut to rectangles, squares or circles, it is after gas cutting. In the case of detail parts made up by the detail parts group, it is at the point where they leave this group. In the case of complicated lay outs of structural sections by the detail parts group, a further inspection is made after lay out and before cutting, punching or drilling.

The second stage is after assembly and tack welding and before any arc welding is done to ensure that all assembly work is correct before finally fusing the parts together. This is to eliminate the risk of having to cut out welds because of faulty assembly work.

The third stage is the actual arc welding inspection and is handled by the arc welding inspector only. This is a continuous procedure as welding progresses, the inspector examining the work as it is being done. He must also see that all welds called for on the drawing are made, that they are of the specified size and length, and that the appearance is the best possible.

The fourth and final inspection is made just prior to the shot-blast cleaning. This is principally one for detail and appearance, insuring against the need for additional work after cleaning and painting. In the case of containers that require to be oil-water-or air-tested, the same procedure is followed, except that the outside of the vessel does not receive the primer coat of paint until after testing. Thus the article is finally inspected for detail, cleaned inside, and out, and given the primer coat of paint inside. Then it is tested, painted outside, and shipped to the final assembly department. The nature of the test is dependent on service requirements.

Wage Payment Plans, Day Rate and Incentive Systems.—One important decision a management is called on to make in organizing a division for arc welded fabrication is the principal upon which the remuneration of its employees will be based, for upon the method chosen and of its application will depend the goodwill of the employees. Two major plans are available. One, the day rate principle, uses a fixed rate for a worker based on time units worked. The other is based on the payment of a fixed sum for a given piece of work, irrespective of the time taken. This plan is better known as the incentive system.

An incentive system of wage payment has been used in the shop with which the writer is connected for the past twenty years, starting when it was known as the "tin shop" with galvanized sheets the usual material, and developing with it to a point where some of the world's largest machines are now fabricated therein. That it has given satisfaction is indicated by the entire absence of friction between the workers and management, and by the complete failure of a number of professional agitators, who have repeatedly tried to stir up trouble amongst our men.

The Group System of Shop Organization.—The arc welding section, along with most of the other departments in the plant, is organized on what has become known as the "group system," in which a number of men doing similar or consecutive operations are banded into a group under a group leader, who is in effect an assistant foreman, in that he has full charge of his gang which may have from three to twenty workers.

The group leader is a workman, who is actually in charge of his group and is the only one to receive instructions from the shop foreman, to handle time and job cards, and generally conduct any conversation or business pertaining to the work with the foreman, cost control man, schedule man or storekeeper.

Generally speaking, the small groups of four to eight persons, all of whom are in close contact and visible each to the other, are the most successful, though a number of larger ones have been outstanding exceptions to this rule.

The advantages of the plan are, a better co-operation between members of a group than between individuals, providing the momentary assistance when required, or the extra hand for a few moments at a critical part of a job, so that it largely eliminates the helpers that are required under individual systems. The few that are required, and that is rarely more than one to a group, are rapidly trained to more valuable work since the quicker a helper can be trained to the higher grades of work, the more he earns for the group. This type of shop organization is specially valuable for one engaged in arc welded fabrication, as this method involves the assembly and welding together of details made from plate, bars, and structural shapes, all of which have first to be cut to size and shape, frequently followed by other contributory operations, such as lay out, punching, drilling or mitering, combined with one or other of the forming processes such as bending, rolling or flanging.

The How and Why of Arc Welded Fabrication.—The first operation in preparing the parts for assembly is the cutting to size and shape

of the various components, so that the efforts to obtain maximum use of the material, with minimum scrappage, must center at this stage. It involves three operations, viz., saw, shear and flame cut. Sawing is merely a matter of cutting bar stocks into desired lengths, and conservation efforts can only see that odd ends are used and not allowed to either accumulate or be thrown out as scrap. The numerous requirements for small pads make this easy of attainment.

While it is desirable to get the highest possible yield from the material used in order to hold down material costs, labor costs are equally important and in many cases can be substantially reduced by minor changes or additions to the equipment. One such help is to insert a standard steel rule into the shear tables, and to graduate the guide and gauge bars on power saws and bar shears, another is to equip the punches with quick setting gauges so that by laying out one piece of work as a master any number of duplicates can be produced by setting the gauge at one side of the punch for one hole and at the other side for a second, thus two holes can be punched in each piece and the gauges reset to the master piece for another pair until all holes are punched. This method is very effective when relatively small lots (12 to 500) pieces are to be produced with single piece weights of 25 pounds or less.

Templates are probably the greatest labor saver that can be used in the preparation of component parts. By their use the time required to mark sections for cutting or punching is often reduced by 50 to 80 per cent of that taken when using rule and square.

The work of assembling the component parts into final form prior to welding is fully as important as the actual welding. Then is determined whether machined faces will clean up or not, whether or not the part will readily take its place in the final assembly, or, in short, if the job will prove satisfactory. The assembly work has much greater cost potentialities than even the welding, and the accuracy of the material specifications and preparation has an important bearing on assembly costs.

The Welder's Job.—At least 95 per cent of all arc welding in the shop under consideration is used to join steel parts together with the parent metal having a carbon content of less than .30 per cent.

The first class operator does more than good welding; he uses his head to keep his work trouble free, declining to proceed with anything that is likely to result in dissatisfaction, without calling his superior's attention to it. Distortion is largely prevented by a welding sequence that avoids fixed or rigid conditions wherever possible; i.e. butt welds, especially longitudinal seams in cylinders, are welded first, followed by girth seams and the ends. The basic principle in all cases is to work out from the center; thus, in a gear blank, the hub is first welded to the web plate. If the web is solid at least four expansion slots are put in it, and in welding the rim to the plate, a start is made at the center of each section travelling both ways to the slot. Evenly distributing the heat is an important help and in many cases is best obtained by having two welders working opposite each other. On light structures, a rapid removal of the heat is very valuable and easily obtained by using heavy

holding fixtures, or by clamping a heavy plate to the work. In many cases welding may be used to reduce slight forming inaccuracies, e.g. tank seams; if they are a trifle high, weld the outside first, if low the inside first, in each case the slight reduction in length caused by contraction will change the contour in the desired direction, though it is then desirable to allow complete cooling before welding the second side.

To follow representative arc welded parts through the fabrication shop, outlining the methods used and the precautions taken to ensure ultimate satisfaction, giving the reasons for such methods and precautions, is probably the best way to give the reader an insight into the work.

Let us first consider a very common article, tanks for small transformers of the distribution type such as may be seen on posts all over the country. Photo, Fig. 3, shows three of these as the welding is completed with the one on the left, and the smallest one built having inside dimensions of 9″ x 12″ x 27″ high. The one on the right is a larger one of the same design, while the center one is the largest of the distribution line and is equipped with cooling tubes.

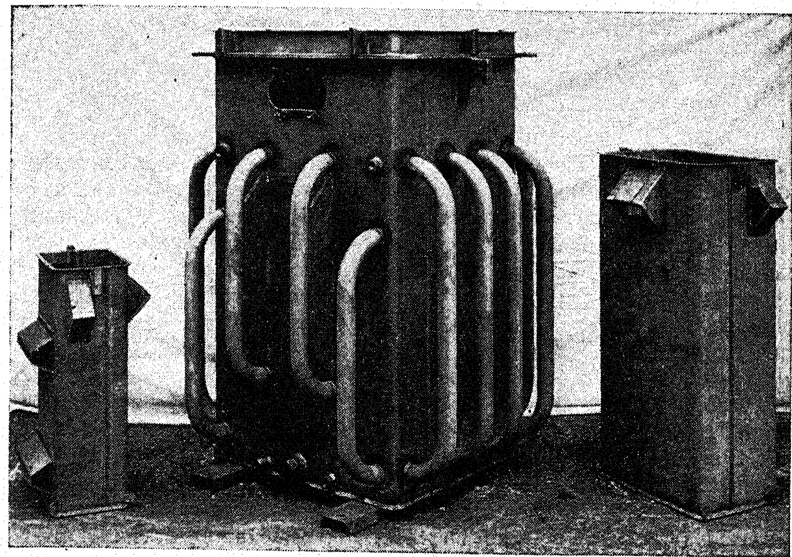


Fig. 3. Arc welded transformer tanks.

Considering the two end ones, the first step is to shear the material to size. Shearing is followed by punching holes for the three pockets that can be seen. The work thus far being done in large quantities, the parts going into stock as sheared and punched wall sheets, to be drawn out as required and made up. Bending, first the flange, then the vertical corners brings them to the welder who welds the seams, holding them in a bar and clamp type fixture to prevent any trace of warpage. Next the bottom is assembled and welded to the walls, thus stiffening the tank for the assembly and welding of, first, the hangers seen on the

left side of the small one, locating them by a welding fixture that uses the bolt holes in the hangers with the top and sides of the tank as location points. Next the pockets are placed and welded, followed by the combination lifting and cover holding lug seen beside the pocket. The four small lugs visible at each lower corner are for shipping purposes while the small boss serves to bolt the grounding terminal. All assembly and welding work on this type of tank is done by the welder, this being the reason for welding each piece immediately after assembly. Cleaning, testing with transformer oil for a minimum of twelve hours, and painting complete the tank.

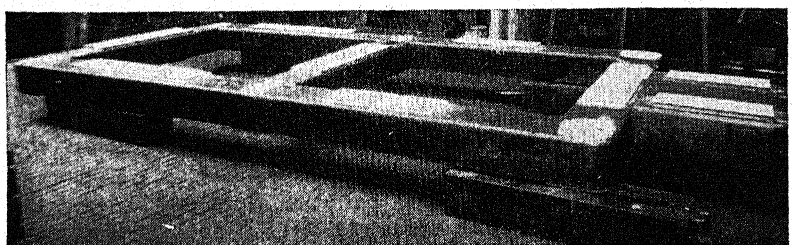


Fig. 4. Arc welded bedplate.

Bedplates are used for an infinite variety of machines and have been built in more ways than probably any other machine part. Fabricated bedplates are usually constructed from structural sections and have a very crude appearance, but the one shown by photo, Fig. 4, is formed entirely from steel plate in a way that combines both attractive appearance and substantial construction with economical fabrication. Except for the pads 3/8″ steel plate is used throughout with construction details as follows. The main members, sides and ends are sheared to lengths equal to outside dimension less 8″ and to a width equal to the sum of its inside sectional dimensions; i.e. a bedplate ten feet long with a "U" section 8″ deep and 12″ wide outside, would have its side members sheared to 112″ long and 26½″ wide, the 8″ shortage being made up by the corner pieces, while the 26½″ dimension is obtained from the inside sizes of twice 7⅝″ plus 11¼″. Following shearing, they are bent cold on a ½″ inside radius, using the press type bender earlier described and standard dies. The next step is to miter each end from a point 4″ back from the outer side to complete the main member preparation. When, as in this case, a cross member is required, it is simultaneously made up with square ends to a length equal to the distance between the inner faces. Meanwhile the pads have been cut to size, as have the ribs, which are simply pieces of 3/8″ plate cut to fit inside the section and act as stiffeners, there being one or two under each pad. The corner pieces are sheared to a template, and hot formed by a single stroke of the press. They are made up in large quantities and kept in stock in standard depths, to eliminate setting up costs. When an extension as seen at the right of bedplate is required, it is made up in a similar manner to the main sections, from a single plate, the corners being cut out prior to bending. On starting to assemble the unit, the

ribs are first placed and tack welded in the sections, then the main members placed to a floor lay out, followed by cross and extension sections if required, then the corner sections are fitted, bevelled, placed, and tack welded. Welding of the pads has a tendency to bow the structure so they are not put on until the other welding has been done, which starts by welding the top side of each joint followed by the vertical welding of the outside welds at each corner while the unit is clamped to the floor. The inside welding is done next, turning it and supporting by jib cranes during this work, after which it is again laid down for the assembly and welding of the pads. The bowing tendency is now overcome by packing up the center and pulling down the ends by clamps, the usual amount being $\frac{1}{16}''$ per foot of length. On completion of welding the shot blasting and application of a coat of primer paint complete the job for delivery to the machine shop.

Arc Welding in the Tool Room.—The use of arc welding by the tool making division as means of producing better tools, dies, jigs and fixtures, at lower costs than was possible by other means, began with the acquisition of our first arc welder some eighteen years ago and grew steadily till the general introduction of the high grade shielded arc type of electrode a few years later, when, due to the phenomenal resultant increase in fatigue and impact strength of the weld metal, it

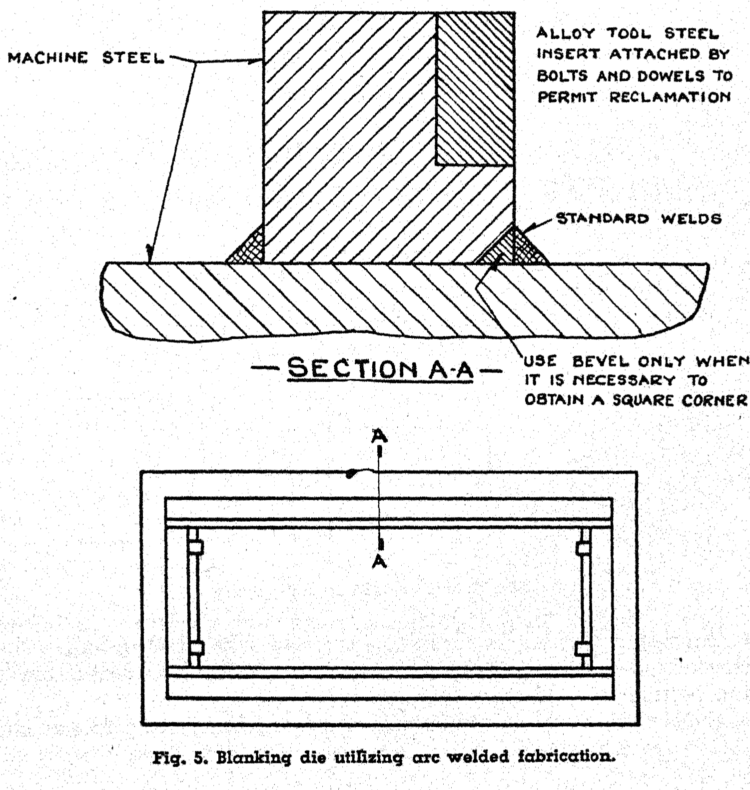


Fig. 5. Blanking die utilizing arc welded fabrication.

became the standard method of making permanent connections, and a portion of the tool room was set aside as an arc welding booth, suitably screened, and a welding unit installed for tool work exclusively.

Specific examples will best serve to show the diversity of application and sketch Fig. 5 indicates how dies whose function is to cut sheet metals are fabricated, using machine steel bars welded to steel plate as a support for the alloy tool steel inserts.

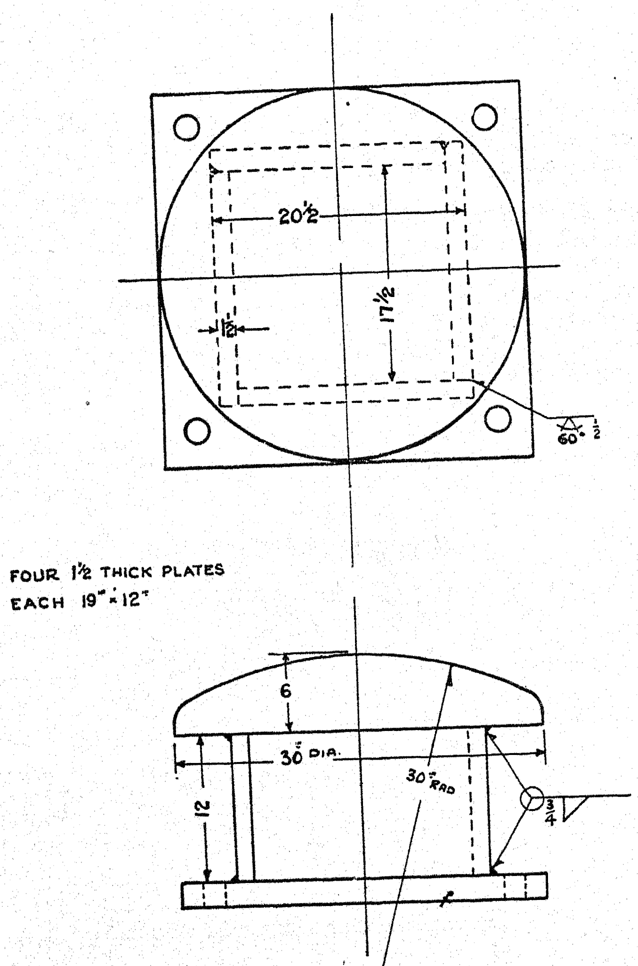


Fig. 6. Arc welded forming punch.

An instance of a heavy forming punch of fabricated and arc welded construction is found as sketch Fig. 6. It is used to form circuit breaker tank bottoms of 3/8″ thick plate.

By far the most important use of arc welding in the tool room is in the production of jigs and fixtures wherein the use of cast iron

was abandoned many years ago, as was the use of bolts and dowels for any permanent connection. All are now made up from steel plates, bars and structural shapes and include jigs for drilling, machining, assembling, inspection, and last, but by no means least, those that hold many jobs during welding operations. The general method follows that used for dies including stress relief. A simple arc welded drill jig, used to drill moulding flasks is a good example of how arc welding makes it possible to have fixtures, even for limited production. On this job interchangeability was desired and ensured by the fixture at a substantial saving as compared to the only other method, viz., the marking of each hole.

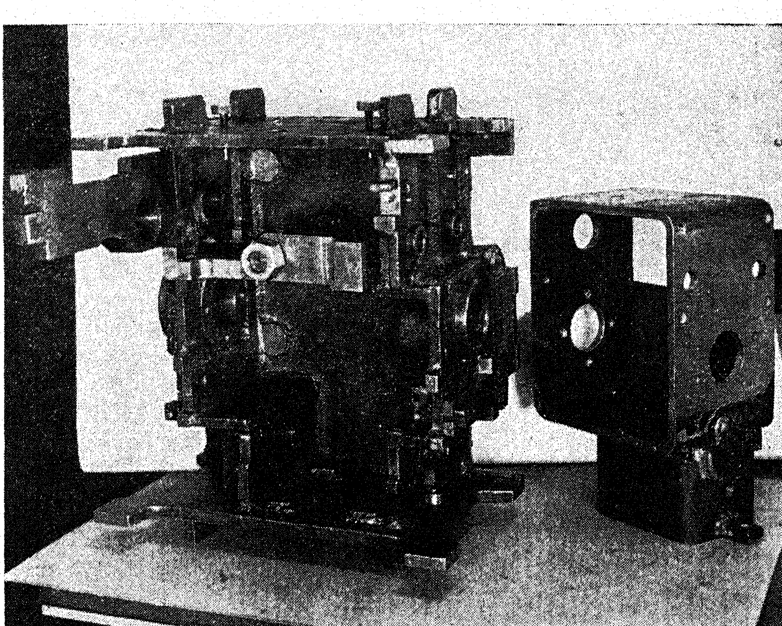


Fig. 7. Arc welded drill jig and the frame it is used to drill.

Photo Fig. 7 shows one of the commonly used box type drill jigs that have been arc welded fabricated for so long that no suitable example could be found to use as an illustration of other methods. This one is used to drill the so-called "Magnet Frames" used to house the solenoids for an electrically operated 600-1200 ampere, 7,500 volt oil circuit breaker. Thirty-two holes, ranging from $\frac{5}{16}$"to $2\frac{1}{4}$" diameter, are drilled in this part by aid of the fixture, with five of the six available surfaces carrying drill bushings. On the right of the photo is one of the drilled frames showing the multiplicity of holes and sizes required. Needless to say, the frame is also of arc welded construction as is the entire apparatus of which it forms a part.

General Plant Equipment Maintenance.—The tool making section have no monopoly on the use of arc welding for plant purposes, full

advantage being taken of it for the production of new and the renewal or repair of existing equipment, by the plant engineer's department.

The liquid carburizer pot is one such example, indicating how a plate is formed to comprise the sides and bottom, to which is arc welded a pair of end plates and a flange made up of 2" by ½" hot rolled steel bar. This article is subjected to very severe service since it forms the business section of a liquid carburizer, used to case harden a large variety of small parts. This design replaces a cast iron pot formerly used that had an average life of just half that now obtained, though the walls were substantially heavier resulting in slower heating.

The examples referred to form only a fraction of one per cent of those available as a result of a vigorous policy of taking full advantage of the arc welding process as a means of saving both time and money on the myriad items that every large plant produces for its own use. A plant weldery is in a very happy position on this class of work, because its facilities combine those of a foundry and a structural steel shop, permitting it to produce almost any metallic article in any form, but it is up to those in charge to both go after the work, and to treat it fairly when they get it.

The Use of Arc Welding in Other Sections of the Plant.—If any proof is needed that arc welding is a universal tool, it is found when consideration is given to the manner in which it is used in the plant as a unit in line production, which is in addition to the manufacture of weldings in the department primarily organized for this purpose and previously described.

In applying it as a part of a production line it is the duty of the welding engineer to co-operate with the designer of the product, the

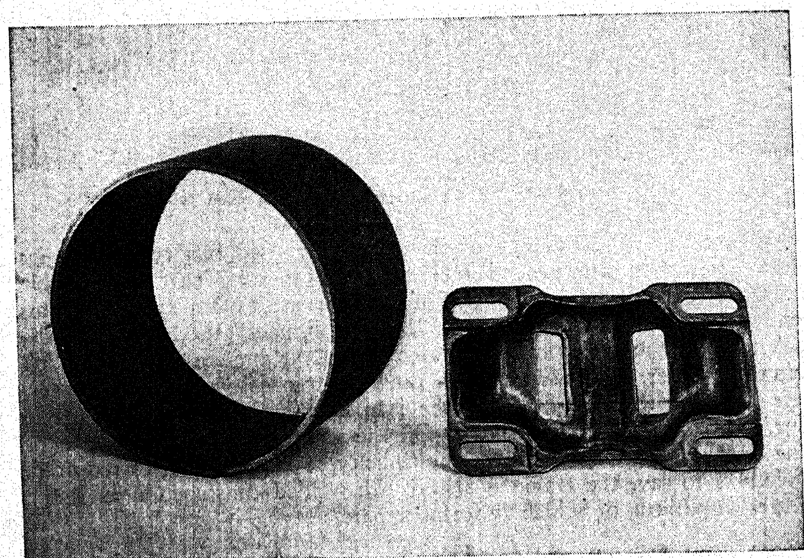


Fig. 8. Parts for arc welded ¼ horsepower motor frame.

plant engineer's staff and the departmental supervision to ensure that the design of part and joint is the most practical possible, and that suitable equipment and fixtures are provided for use by well trained operators working in a safe and efficient manner. The multiplicity of product and problem prevent any stereotyped solution so that consideration of specific examples is required to give the reader an impression of what has and can be done.

The first of such application was in a line producing one-quarter horsepower electric motors of a type largely used to drive domestic washing machines. In this case a cast iron frame weighing 6½ pounds and necessarily produced in a foundry at some distance from the assembly line, was replaced by a fabricated frame weighing 4 pounds and produced on the line which eliminates production stops for lack of this part, to say nothing of the 3 machining operations requiring a total of 7 minutes reduced to a single one done in 1-1/10 minutes. Photo, Fig. 8, shows the component parts of the redesigned and fabricated frame, consisting of a cylindrical section housing the stator punchings, and a press formed foot section.

Our outstanding application of arc welding to line production is in the fabrication of food compartment liners for electric refrigerators and oven liners for electric ranges. The problem was one of welding the .037″ stock and producing a weld that would take a vitreous enamel coating at least as well as the special enameling stock of which the parts were made. Prior to the adoption of arc welding they were

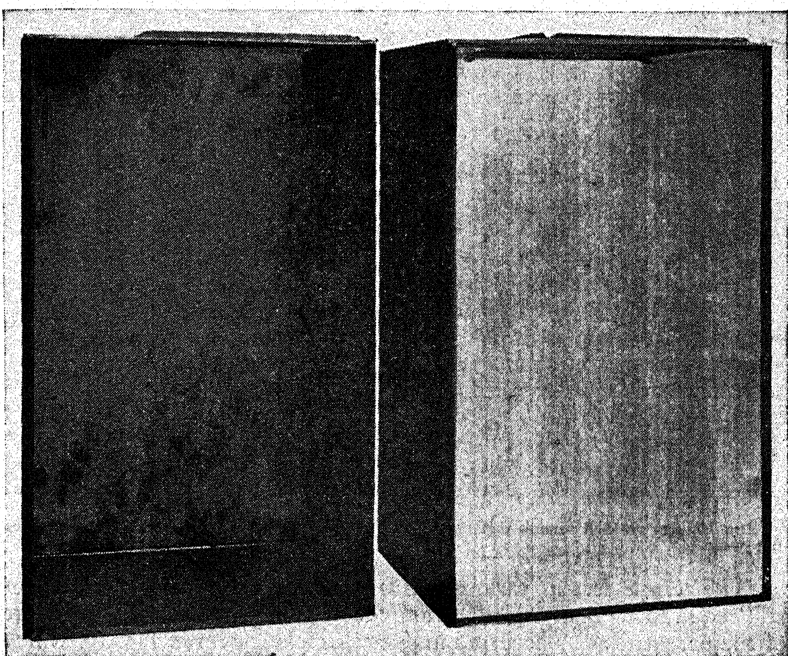


Fig. 9. Arc welded refrigerator food compartments before and after enameling.

produced by another fusion welding process, with a welding speed of six inches per minute, and refirings during enameling, due to defects over the welds, of from nine to ten per cent of total production. This was changed to a welding speed of 22 to 23 inches per minute with refirings of less than one per cent, while not one box has gone to the scrap pile because of welds that would not enamel. A refrigerator food compartment is made up of three pieces of sheet steel, one forming the back and sides, by bending to form the rear vertical corners, the other two being end pieces that must be welded to the body or skirt section.

Photo Fig. 9 shows a pair of such arc welded food compartment liners, one before and one after vitreous enamelling, with the welds clearly visible in the one and covered with enamel in the other, so that it is very difficult to distinguish between the bent and welded corners.

Tests and Testing.—The testing of materials includes both the metal to be welded and the metal deposited or affected by the process used, hence material tests are made of all plate stocks as they arrive in the plant. The many forms of broken fillet, nick break, tensile, bend, impact, and corrosion tests, macro and micro examinations, are used for testing welds.

Nick-break butt weld and broken fillet weld tests are considered the most valuable tests that can be applied because they reveal the most frequently found ills of lack of fusion, slag inclusions, or gas pockets, and are used in the maintenance of operator standards as earlier outlined.

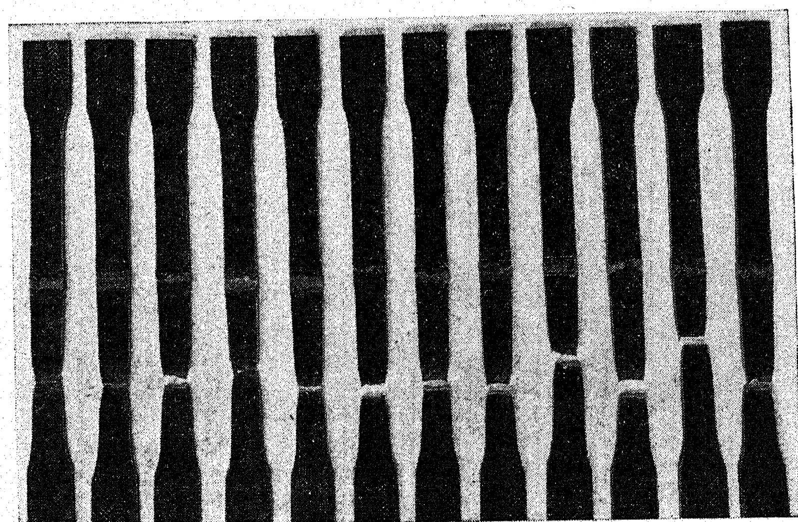


Fig. 10. Arc welded tensile test specimens, all of which failed at some distance from the weld.

The tensile test in various forms has been extensively used and is still required by many qualification codes. The usual result is a failure of the parent such as occurred in every sample shown in Fig. 10, which shows some of those made when qualifying our operators for Class II work under the A.S.M.E. code.

The test most frequently used to obtain information as to the physical properties of arc weld deposited metal is the standard .505 diameter all-weld-metal tensile test.

This latest development is a true all-weld-metal test with the same form as the standard .505″ diameter but having a test section only .154″ diameter with 1/4″ diameter ends and an overall length of only 1 1/8″.

The bend test is regularly used as a complement to the tensile tests as a means of obtaining ductility values not supplied by them. Its usual form is that of a butt weld from which the reinforcement has been machined off both sides and the corners removed to a radius not over 1/10″ thickness. It is then lightly macro-etched to exactly locate the weld and faint lines drawn across at the edges. Careful measurements to determine the exact width of the weld are made and recorded, followed by a free bending of the specimen with the weld in the center of the stressed portion. Bending is continued until a visible crack appears, at which point the stress is removed and the width of the weld again measured and the percentage elongation of the outer fibres calculated from the data obtained. While the A.S.M.E. code specifies a minimum of 30% elongation, from 40 to 60 per cent are regularly obtained on material 3/4″ and over in thickness when using high grade down hand types of electrodes.

The impact test, in either the Izod or Charpy form, is primarily a developmental and research test and is not extensively used in routine work. But information as to the values obtained from the procedure, and electrodes being used, has considerable value to the selling staff and should be obtained for this purpose and checked at intervals of one or two years or whenever changes are made that may have appreciable effects on the values. All-weld-metal samples are preferred for this work in order to have true results, though they have the same objections as apply to .505 tensile tests, viz., that only normalized metal can be tested. Recent Izod test values show 50 to 60 for down hand rod welds and 35 to 50 for electrodes used in fillet weld work. The standard square sample with vee notch is used in each case.

This is another of what might be well termed educational tests, since its main value is in sales and demonstration work, particularly in showing the superiority of the covered rod process as against both the parent metals and the orginal bare rod method. A test, combining welds made by both types of electrodes, is very enlightening to a group who, though active in the metallic industry, may not be in close touch with the progress made by the arc welding section. The standard test of 72 hours immersion in a 50% solution of hydrochloric acid and water, at 160 degrees Fahr., is usually used bringing out the resistance of the high grade weld metal in a very effective manner.

The fatigue test is rarely if ever used as an arc welding test in other than research work, or on some special problem.

The use of the macro-etched sample to reveal depth of penetration, degree of fusion, the extent to which subsequent beads or layers bit into the earlier ones, as well as the extent to which normalization took place, is productive of much valuable information, particularly in determining the relative values of slightly different procedures. It clearly shows how the weld was deposited, how fusion took place and, by the

presence or absence of the typical dendritic lines, whether or not complete normalization of the inner layers was affected.

The use of a microscope in welding operations is desirable but not mandatory. Its principal value is along educational lines and for this reason a small one that can be set up in the shop or office is most useful. There is no need to have a shop microscope with more than 250 diameters.

Apart from its educational value, the principal use of the low power microscope is to extend the usefulness of the macro-etched samples. In many cases it is desirable to examine an inclusion or questionable area in greater detail than a hand glass permits, and it is a real help to get such a sample under low magnification.

Arc Welding Speeds and Costs, How Allowed Times Are Established.—The basic requirement for any incentive plan of wage payment as applied to arc welding is an accurate knowledge of the welding speeds obtainable under the conditions existing in the shop wherein the work must be done.

When an electrode is adopted as a standard, tests are made to determine the optimum current values for each size to be used. These consist of deposit ratio-arcing time tests in suitable steps, as shown by chart "FA." The prefix F indicates the rod to be fillet position one, D being used for downhand or butt welding types, and A for all position rods.

In test, (Small Table, top Page 786), the optimum value for a 3/16" rod was 210 amperes and 270 amperes for a 1/4". Higher currents increased costs, both for arcing and cleaning times, in addition to increased electrode costs. In some cases it is profitable to use values somewhat below the optimum as the time required to remove the greater number of particles from adjacent surfaces more than offsets the lower arcing times. Chart "FB" is partially prepared from the information in "FA" and completed from standard data obtained from job time studies. It shows the time in decimal hours required to place an electrode in the holder, the actual arcing time per rod at the given current values, and the time required to remove the slag from the weld produced by one electrode. This latter is always obtained from actual job studies with the electrode being checked and is not taken from the test welds. These three values are added together to obtain the total actual time required for each electrode used. To this total is added a fatigue and personal allowance of 25% and the resultant value is the allowed time given the operators for each electrode they must use. The need for a personal and fatigue factor is generally recognized but the amount is open to discussion. The writer feels that 25% is the minimum, consistent with fair dealing and happy operators. It has been in effect in our shop since 1930, proving satisfactory to employees and management, hence it is recommended as a fair value.

Convenience requires the reduction of the time per electrode into one of times per inch of weld, while inspection and supervision requires

CHART FA

Deposit Ratio and Arcing Time Test Results on Electrode Type F. No. 4 (Fillet Welding Rod)

Test made on 300 ampere 40 volt single operator machine No. 3 (10-22-36)

Electrode Diameter Length and Number per Pound	Amperes Used	Deposit Ratio	Average Arcing Time per Electrode: In Decimal Hours	Average Arcing Time per Electrode: In Seconds	Arcing Time in Decimal Hours per Pound of Weld Metal Deposited	Arcing Time per Pound in Minutes and Seconds: Minutes		Arcing Time per Pound in Minutes and Seconds: Seconds
1/8" dia. 14" long per pound.	100	.7041	.0219	79	.5536	33	—	13
	110	.6925	.01995	72	.5006	30	—	2
	120	.6810	.0179	64½	.4659	27	—	57
	130	.6694	.0166	60	.4390	26	—	20
5/32" dia. 14" long per pound.	140	.7132	.0205	74	.3424	20	—	33
	160	.6925	.0178	64	.3084	18	—	30
	180	.6615	.0163	58½	.2934	17	—	36
3/16" dia. 18" long per pound.	170	.6837	.0314	113	.2859	17	—	9
	190	.6734	.0283	102	.2649	15	—	54
	210	.6435	.0256	92	.2461	14	—	46
	230	.6274	.0232	83½	.2330	13	—	59
1/4" dia. 18" long per pound.	280	.6876	.0320	115	.1619	9	—	43
	300	.6741	.0302	109	.1560	9	—	22
	310	.6672	.0293	105½	.1537	9	—	13
	320	.6604	.0281	101	.1484	8	—	54

Electrode Diameter and Length	Current in Amperes	Deposit Ratio	Arcing Time per Pound of Deposited Metal	Average Arcing Time per Electrode
3/16" — 14"	190	.5938	.2680	.0228
	210	.5814	.2129	.0196
	230	.5457	.2239	.0174
1/4" — 14"	250	.5961	.1715	.0257
	270	.5858	.1475	.0229
	290	.5589	.1548	.0216

a knowledge of how many inches of weld should be obtained from one electrode. Both are supplied by simple calculations, as follows:

Divide the weight of weld metal resulting from the test made at the optimum current value, by the number of electrodes used, obtaining the weight of weld metal deposited from one electrode. This is recorded as chart "FC." Then divide the weight of deposited metal obtained

CHART FB

Applies to Fillet Welds Only
Actual and Allowed Times per Electrode
All Times in Decimal Hours

Figures in brackets are the equivalent times in seconds.

Electrode Diameter and Length in Inches	Place Rod in Holder	Arcing Time	Remove Slag and Particles	Total Per Rod	25% Allowance	Allowed Time in Decimal Hours
1/8" × 14"	.0025 (9)	.0166 (59.8)	.0060 (21.6)	.0251 (90.4)	.0063 (22.7)	.0314 (113)
5/32" × 14"	.0025 (9)	.0163 (58.7)	.0060 (21.6)	.0248 (89.3)	.0062 (22.3)	.0310 (112)
3/16" × 18"	.0030 (10.8)	.0232 (83.5)	.0065 (23.4)	.0327 (117.7)	.0082 (29.5)	.0409 (147)
1/4" × 18"	.0032 (11.5)	.0281 (101.2)	.0075 (27.0)	.0388 (139.7)	.0097 (34.9)	.0485 (175)

from one electrode by the per inch weight of each size of weld, for which the given size of electrode is used. This gives the number of inches of each size of weld that may be obtained from one electrode, if the operator were able to produce welds of exact size and shape. Since no operator can produce a given length of a given weld from each and every

CHART FC
WEIGHT OF WELD METAL DEPOSITED BY ONE ELECTRODE OF TYPE P. NO. 4

1/8" dia. 14" long 130 amperes 71% Deposit Ratio produces .03775 pounds per electrode.
5/32" dia. 14" long 180 amperes 66% Deposit Ratio produces .05555 pounds per electrode.
3/16" dia. 18" long 230 amperes 63% Deposit Ratio produces .1166 pounds per electrode.
1/4" dia. 18" long 320 amperes 66% Deposit Ratio produces .1895 pounds per electrode.

electrode he uses, a range is necessary and he is given a minimum and maximum length between which he is expected to work. The maximum length given is that which results in the correct size required. The minimum number of inches of weld per electrode is obtained by adding to the actual weight of a weld an oversize factor, the result being used to again divide the produced weight per electrode and obtain therefrom a figure that is the minimum length of weld to be obtained from each electrode. This oversize factor, detailed on chart "FD," is largely the result of experience in developing the system, and is much higher for the smaller sizes than for the larger. Since this is a standard or base chart, factors and weights are given for both normal and vee position fillets, though the electrode in question is used for normal position work only. The allowance for vee position work is somewhat lower than for normal because of the better control that is possible. The last four columns show the weights of fillet welds after the addition of the oversize factor. Chart "FE" shows the results from the next step in which minimum and maximum weights shown on chart "FD" have been divided into the weight of metal obtained from one electrode, chart "FC," to obtain the maximum and minimum lengths of weld from one electrode, and every operator must consistently come between the two values and must not be near the maximum on more than the occasional rod, it being our intention to make all welds slightly oversize, though holding the additional metal within reasonable limits. The last column is included to permit rapid calculation of the electrode requirements for any job under consideration for cost or estimate purposes. The weight of electrodes needed being supplied by a simple division of the weld lengths by the number of inches of weld obtained per pound of rod. The given figures are based on an average of the maximum and minimum length obtained from each electrode. The allowed times per inch of weld are based on the minimum length per electrode, and are obtained by dividing the allowed time per electrode by the shortest length to be obtained from it and the results of this calculation for the electrode under consideration are shown as chart "FF." The times given are not, and are not intended to be, the shortest time in which the given size welds can be made, but are reasonable times that can be met by a welder day in and day out. They give him the benefit of the permissible variation per electrode by the use of the shortest length he may obtain as the dividing factor to obtain the per inch times; they further allow 25% of the actual times for fatigue and personal requirements as shown by chart "FB." They are applied to all fillet welds except circular fittings such as pipes under 4″ in diameter, and cover only the three factors of, insert electrode in holder, pass the electrode through the arc, and remove the residual slag and metal particles, leaving a clean, neat appearing weld. The last column is included as a result of a request by the operators for convenient figures on the basis of an hour's work, as they can better visualize a given number of feet per hour than a time value per inch. Any such request for additional data is always granted as a part of the open book policy that has and does create mutual confidence. No tack welding is included in any welding time, as this is considered an assembly operation.

CHART FD

WEIGHT OF FILLET WELDS

Weld Size Inches	Actual or the Minimum Allowable Weights in Pounds		Allowed Oversize Factor		Maximum Allowed Weight in Pounds			
					Normal Position		Vee Position	
	Per Foot	Per Inch	Normal Position	Vee Position	Per Foot	Per Inch	Per Foot	Per Inch
1/8	.0265	.00221	30%	25%	.03445	.00287	.0331	.00276
3/16	.060	.00500	25%	20%	.075	.00625	.072	.006
1/4	.106	.00883	20%	15%	.127	.0106	.1219	.0102
5/16	.166	.01383	15%	15%	.191	.016	.191	.016
3/8	.239	.01992	15%	10%	.275	.023	.263	.022
1/2	.425	.0354	15%	10%	.489	.041	.467	.039
5/8	.664	.0553	15%	10%	.764	.064	.730	.061
3/4	.956	.0796	10%	7½%	1.052	.088	1.028	.087
7/8	1.302	.1085	10%	7½%	1.432	.119	1.400	.117
1	1.700	.1417	10%	7½%	1.870	.156	1.825	.152

CHART FE

NO. OF INCHES OF NORMAL POSITION FILLET WELD TO BE OBTAINED FROM ONE TYPE F. NO. 4 ELECTRODE—ALL DIMENSIONS IN INCHES

Weld Size Inches	Electrode Diameter Inches	Electrode Length Inches	Maximum Length any Position	Minimum Length any Position	Amperes to be used with 40 volt machine	Number of Electrodes in one pound	Average Number of Ins. of weld from one pound of electrodes
1/8	1/8	14	17	13¼	130	17.72	268
3/16	5/32	14	11	9	190	11.64	116
1/4	3/16	18	13¼	11	250	6.17	75
5/16	3/16	18	8½	7¼	250	6.17	48
3/8	1/4	18	9½	8¼	320	3.05	27
1/2	1/4	18	5⅜	4⅝	320		15
5/8	1/4	18	3½	3	320		10
3/4	1/4	18	2⅜	2⅛	320		7
7/8	1/4	18	1¾	1⅝	320		5
1	1/4	18	1⅜	1¼	320		4

Lengths calculated in each case to the nearest ¼ inch for welds up to ½ inch.

CHART FF

ALLOWED TIME PER LINEAR INCH OF FILLET WELD

Obtained by dividing the allowed time per electrode (chart "FB")
by the minimum length obtained from each electrode (chart "FE")

Weld Size Inches	Allowed Time per Inch In Dec. Hours	In Seconds	Electrode Diameter	Feet and Inches per Hour Feet	Inches
1/8	.0024	7.6	1/8	34 —	9
3/16	.0035	12.6	5/32	23 —	10
1/4	.0037	13.3	3/16	22 —	6
5/16	.0057	20.5	3/16	14 —	7
3/8	.0059	21.2	1/4	14 —	2
1/2	.0105	37.8	1/4	7 —	11
5/8	.0162	58.3	1/4	5 —	2
3/4	.0228	82.1	1/4	3 —	8
7/8	.0306	110.2	1/4	2 —	9
1	.0388	139.7	1/4	2 —	2

The time required to turn the part or otherwise handle it is separately considered and has been the subject of numerous time studies, from which has been developed the unit allowances given as Chart "G". This covers practically all handling conditions that occur in the shop and any new ones that appear are checked and added.

CHART G

TABLE OF ARC WELDING HANDLING TIMES

	In Decimal Hours	In Minutes and Seconds Minutes	Seconds
To mark length, start and stop each weld in intermittent welding	.0100	0 -	36
Turn light job by hand	.0150	0 -	54
Turn medium job by hand jib, under 1000 pounds	.0600	3 -	36
1000 to 3000 pounds	.1200	7 -	12
Turn heavy job by crane, 3000 - 10,000 pounds	.1500	9 -	0
Over 10,000 pounds	.3000	18 -	0
Move from one weld to another	.0150	0 -	54
Place 3 foot high platform	.0500	3 -	0
Place 6 foot high platform	.1000	6 -	0
Place 9 foot high platform with crane	.2500	15 -	0
Wait for crane	.0900 hr.	5 -	24
Place and remove one clamp held by one 1 inch bolt	.0800 hr.	4 -	48
Place and remove dog clamp	.0200 hr.	1 -	12
Set up time (get card group leader)	.0800	4 -	48
Start job, includes moving electrodes, holder and cable, hand tools, etc., to starting point	.0800	4 -	48

Estimating, Cost Determination, and Records.—The only reason for organizing a company, acquiring plants and equipment, building up a personnel, developing products, and selling and servicing them, is to produce the goods for less money than that for which they may be sold, leaving a balance known as profit. Selling prices are largely fixed by competition; therefore, costs are the determining factor as to whether the organization is a success or a failure, and whether or not it can stay in business, providing remuneration and security for both the employees and the capital invested in it. For this reason the constant accumulation of cost data may be likened to the nervous system in the human body, the channels through which the information is brought to the central point, paralleling the nerve threads in indicating the points in need of attention; supplied by the company's officials in one case and the human brain in the other.

The first step is the acquisition of accurate information as to the time required to perform the various operations, and the detailed time study is an indispensable means of obtaining it. The particular type of time study consists of breaking down the work into its fundamental movements and recording the times required by each action. At the conclusion of the study the times are totalled and averaged, and each element recorded on the reverse side of the sheet, together with its unit time and number of times it occurs in the completion of one article. The unit of time used is one ten-thousandth of an hour, slightly over ⅓ of a second, and common practice is to omit the decimal point and treat the figure as a unit, 10,000 of which equal one hour; thus .0029 in a study becomes 29, while 0.290 becomes 290, and .2900 is written 2900. Time values obtained are corrected for skill, effort, and conditions, being raised for better than average factors and lowered for less. The completed study is numbered and filed for future use, either as a reference or as a part of a formula. A typical example of such a study is shown in Fig. 11. The method of acquiring basic arc welding data was previously outlined so there is rarely any need to study welding except when it is only a minor part of the job. The basic data for all supplementary operations is obtained in this way and recorded in a readily available manner by filing the studies under the operations they cover with a cross index reference under the type of product.

All work cards pass over the cost control man's desk to have the allowed times for each operation entered thereon. In most cases this only involves looking up the standard time record card, (See top, Fig. 12), and copying the established time on to the order card for each operation. "Standard Time Record" cards are filed under drawing numbers with only new drawings requiring establishment of times. This is done by reference to formula or previously taken studies on similar work, and calculating the times from them. In order that these calculations shall be available if required, they are made out on form 1324, a completed copy of which is shown at bottom of Fig. 12. This also is a standard form used by all branches of the plant; hence, some of the items in the upper right corner are not applicable to fabrication work and are simply ignored. They are filed under the drawing number in the user's file. The standard time records are then written out in ink, initialed by the person

DATE 2-14-38
STUDY NO. 1143
SHEET NO. 1
OF 1 SHEETS

ELEMENTS:
1. Assemble Bottom Rim to fixture
2. Tack Weld Rim Joint
3. Place and tack weld fans vane
4. Assemble one support lug
5. Tack Weld one support lug
6. Assemble Hub to Supports
7. Tack Weld Hub to Supports
8. Tack Weld Joint in Top Rim
9. Place and Tack Weld Top Rim
10. Remove tack welded blower from fixture

NUMBER / LINE	1 (T R)	2 (T R)	3 (T R)	3 (T R)	3 (T R)	3 (T R)	3 (T R)	4 (T R)	5 (T R)	6 (T R)	7 (T R)	8 (T R)	9 (T R)	10 (T R)
1	100 100	53 153	84 237	76 313	73 386	64 450	88 538							
2			92 630	76 706	81 787	89 876	68 944							
3			72 1018	87 1105	77 1182	83 1265	90 1355							
4			75 1430	96 1526	80 1606	86 1692	78 1770	117 1887	71 2225					
5								108 1995	63 2359					
6	112 344	51 507	78 585	83 668	90 758	74 832	80 912	112 2107	68 2427					
7			85 912	91 1088	70 1158	78 1236	85 1321	118 2225	74 2501	140 2641	149 2790	133 2923	371 3294	50 344
8			72 1321	87 2300	83 2470	80 2550	82 2632							
9			90 2722	80 2802	79 2881	87 2968	91 59	115 174	80 512					
10								120 294	70 662					
11	104 1642	49 1795	73 1868	80 1948	84 2032	69 2101	77 2178	107 401	73 735					
12			82 2272	93 2357	81 2438	78 2516	84 2600	111 512	67 802	150 952	143 1095	129 1224	340 1564	60 1642
13			87 2606	71 2758	79 2837	85 2922	90 12							
14			79 12	80 171	88 259	82 341	72 413	109 522	69 855					
15								117 639	75 999					
16	The above times are in							114 753	80 1079					
17	decimal hours.							102 855	76 1155	162 1317	151 1468	128 1596	353 1949	57 2006
18														
19	See other side for completion of study													
20														

SUMMARY

	1	2	3					4	5	6	7	8	9	10
TOTALS "T"	0316	0153	4874					1350	0866	0452	0443	0408	1064	8167
No. Observations	3	3	60					12	12	3	3	3	3	3
AVERAGE "T"	0105	0051	0081					0112	0072	0151	0148	0136	0355	6056
MINIMUM "T"	0100	0049	0064					0102	0063	0140	0143	0128	0340	0050
MAXIMUM "T"	0112	0053	0096					0120	0080	0162	0151	0147	0371	0060
Rating (S E C & C)														
LEVELING FACTOR	1.16													
L. F. X AVE "T"	0122	0059	0094					0130	0083	0175	0164	0158	0412	0065
% ALLOWANCE	10													
TIME ALLOWED	0134	0065	0103					0143	0091	0193	0180	0174	0453	0071

FOREIGN ELEMENTS

SYM	R	T	DESCRIPTION
A	2300 / 1393	907	Personal Requirements
B			
C			
D			
E			
F			
G			
H			
I			
J			
K			
L			
M			
N			
O			

SKILL: A1, A2 SUPER; B1, B2 EXCELLENT ✓; C1, C2 GOOD; D AVERAGE; E1, E2 FAIR; F1, F2 POOR

EFFORT: A1, A2 KILLING; B1, B2 EXCELLENT ✓; C1, C2 GOOD; D AVERAGE; E1, E2 FAIR; F1, F2 POOR

CONDITIONS: A IDEAL; B EXCELLENT ✓; C GOOD; D AVERAGE; E FAIR; F POOR

CONSISTENCY: A PERFECT; B EXCELLENT ✓; C GOOD; D AVERAGE; E FAIR; F POOR

GENERAL RATING FOR STUDY	SKILL	EFFORT	COND	CONSY
	+08	+05	+02	+01

STUDY STARTED	STUDY FINISHED	OVERALL TIME
9^07 A.M.	10^13 A.M.	1.100 HRS

Fig. 11. Time study sheet. See page 791b for balance of study.

STUDY No. 1143 DATE 2-7-38

OPERATION Assemble and tack weld Blower complete

DEPARTMENT A-2

OPERATOR MAN ——— NAME R. Haswell NO. A-987

EQUIPMENT

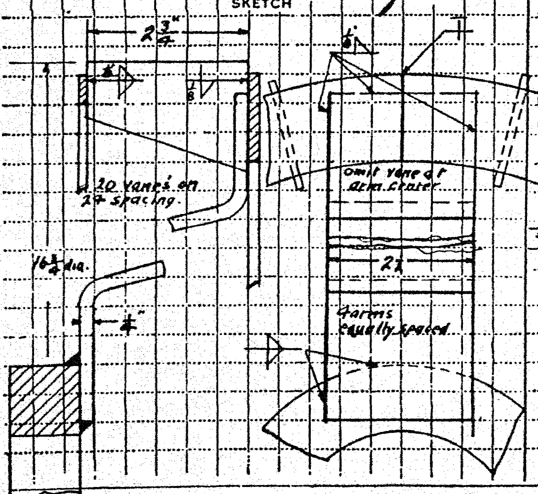
MACHINE TOOL NO. ———

SPECIAL TOOLS JIGS, FIXTURES, ETC Assembly + Welding Fixture #A-1678

CONDITIONS Hand tools in good condition Location clean, Material handy.

OBSERVER R. Smith APPROVED BY H.R.Y.

SKETCH



DWG 571187 SUB. 1
~~MOULD~~ DIE ——— STYLE H-34798 ITEM 2706
~~PATTERN~~ INS SPEC ——— L SPEC SUB.
PART DESCRIPTION Induction Motor Blower
S.O. 898476 MATERIAL 1/8th Sheet Steel

No.	ELEMENTS	SMALL TOOL NOS. FEED SPEED. DEPTH. OF CUT ETC.	ELEMENTAL TIME ALLOWED (BOTTOM LINE OTHER SIDE)	OCCURRENCES PER PIECE OR CYCLE	TOTAL TIME ALLOWED
1	Assemble Ring onto fixture			1	.0134
2	Tack weld Ring joint			1	.0065
3	Place + tack weld one vane		.0103	20	.2060
4	Assemble one support lug		.0143	4	.0572
5	Tack weld one support lug		.0091	4	.0364
6	Assemble hub to supports			1	.0193
7	Tack weld hub to supports			1	.0180
8	" " joint in top ring			1	.0174
9	Place + tack weld top ring			1	.0453
10	Remove complete blower from fixture			1	.0071

The above times are in decimal hours.

~~TIME ALLOWED FIRST PC~~ Set Up .250 EACH ~~ADD'L~~ PC .4266 TOTAL .4266

REMARKS See other side for time details.

Fig. 11. Time study sheet. See also page 791a.

who has made the calculations, and sent to the cost control office, where it constitutes an original, a typed copy being returned to the shop office for use on future orders. Should the available data be insufficient for the establishment of permanent allowed times, a temporary allowed time is set by estimation effective for that order or run and the work card going out to the group is stamped, "Time Study Required." This obligates each group leader to notify the cost control man before starting the work so that the study may be obtained. Should the study indicate that the permanent value should be lower than the temporary one, the higher estimated value stands for that run or order, whichever is completed first, but if the study shows a higher than estimated value then it is made retroactive to the first piece of the run or order, whichever is the greater.

Should it ever be necessary to change a time value, a new card is made out, clearly stating the reasons for the change, and sent, together with the typed copy of the original, to the central office where it replaces

FORM 1285 H.J.R. STANDARD TIME RECORD ROUTING NO.

CARD NO. 1 NO. OF CARDS 1 | SEC. A-2 | DATE 4-27-38 | DWG. 550094 | SUB. 2

MOULD ---- | STYLE PATTERN ---- | L. SPEC. ---- | SUB -

PART AND MATERIAL 1500 K.V.A. Transformer Tank | ITEM NO. 1 to 17

OPR'N NO.	DESCRIPTION OF OPERATION	STD. TIME (MAN HRS) SET UP	EACH PIECE	CLASS OF LABOR	DIE OR MACHINE	HOW SET
1	Item 1 Shear	.100	.190	M	---	F-3
2	" 16 "	.050	.040	M	---	"
3	" 3 Flame cut to shape	.100	.600	M	---	F-6
4	" 4 Flame cut and bevel	.100	.090	M	---	"
	Items 1 to 17					
5	Flame cut for fittings					
	after assembly	.100	.300	M	---	F-7
6	Lay out, roll, assemble					
	and tack weld complete	.250	18.000	M	---	S-196
7	Arc Weld complete	.080	17.000	M	---	F-8

FORM 1324 WORKS DEPT. STANDARD TIME ROUTING NO.

DWG. TITLE D. C. Generator | SEC. A-2 | STYLE PATTERN — | DWG. NO. 570868 | SUB. 1

PART Bedplate (3200 lbs) | INS. SPEC. — | ITEM 1 To 13

MTL. SIZE PCS. PER 100 LBS. — | DIE MOULD — | L. SPEC. | SUB.

MACH. TOOL AND NO. | SPEC. TOOL OR FIXT. — | SET UP [redacted] | STANDARD TIME EACH ~~ADD'L~~ PIECE

OPERATION Arc. Weld Complete | OPERN. NO. 6 | CLASS OF LABOR M | HOW SET F-8 | .0800 | 12.350 *

4 CORNERS - EACH 44½" OF ⅜" SINGLE VEE BUTT WELD 178" AT .0142 2.5276

10 PADS - 4 WITH 42 INCHES = 168
2 " 52 " = 104
2 " 40 " = 80 ⅜ FILLET WELD
1 " 38 " = 38
1 " 28 " = 28
418 INCHES AT .0059" 2.4662

14 BRACES EACH WITH 52 INCHES OF ⅜ FILLET AT .0059 (728" TOTAL) 4.2952

START JOB .0800
SIX CRANE TURNS AT .0800 + .1500 = 1.3800
MOVE TO NEXT WELD 64 TIMES AT .0150 = .9600
PLACE & BOLT 8 CLAMPS AT .0800 .6400
12.3490

RECORDED—[redacted] COST CLERK DATE SIGNED RATE DEPT.

3-21-38 By R.S. 3-21-38 R. Smith

Fig. 12. Standard time records.

the former one, and a new copy that also shows the change and reasons sent to the shop. If a new calculation slip is required it must be attached to the old one, or a notation may be made on the original if space is available. Changes in allowed times are only permitted when there is a change in design, equipment, or standards, that substantially affect the amount of work involved, minor changes of little importance are not allowed as an excuse for downward disproportionate revisions. The setting of the allowed time is an important step in cost control work, since it establishes the cost for that operation for as long as it shall continue to be made by the method prevailing at that moment, and extreme care is taken to have all factors thoroughly understood.

A formula may be made up by combining the information from a number of time studies, taken over a representative range of the work the formula is desired to cover. In making up a formula for time setting, the first step is to separate constant and variable values, adopting permanent values for constant elements and covering variables by curves or charts.

When, as a result of conferences between sales and engineering divisions, a decision is made to proceed with a new, or to re-design an existing, line of products, the drawings are either changed or made up. If this is not practical, engineering department sketches are prepared and a request is made to the shop management for a detailed estimate, stating what is desired and the quantity to be built per order. If special tools, dies, or fixtures are likely to be required, it goes first to the tool design, who check as to which existing tools could be used and estimate the cost of any others required, stating clearly the work they will do. Then with the above information available, the cost control division takes hold and distributes it to their representatives in every section that might possibly have work on it. If more than one department can reasonably do a given operation, both get a chance at it, particularly on borderline jobs. The estimate moves in the same manner as the job does, first to material preparation sections, then through the machining and final assembly parts of the plant, with each cost control man covering the same part of the estimate that his division will do on the job. The first step is an analysis of the work to be done and the means for doing it, paying attention to the material specified to ensure obtaining the most economical form. Procedures, tools, and methods are discussed with both the foreman and in the case of welded fabrication with the welding engineer, and the decisions so made are noted in the estimate immediately following the operations they affect. A request may be made for a change in the design of some part to permit lower cost production, or suggestions to change the entire part are at times a result of shop consideration. These are welcomed and the reasons given careful consideration by the designers, who are pleased to make any possible profitable change. The final shop step is to estimate the labor in exactly the same way that allowed times are set for a job, reporting the result to the cost control office in the manner indicated by the following table.

LABOR AND MATERIAL ESTIMATE
Department A-2

BEDPLATE
Base on 10 per order

Group	Item		Time (In Decimal Hours)	Rate	Estimated Cost ($)
	1	1—Body from $46\frac{7}{8}$ x $25\frac{1}{2}$ of $\frac{1}{4}$ thick steel plate. 85 lbs. each.			
1		Shear at .050 ea. Set up .100......	.060	.66	.0396
2		Bend at .080 ea. Set up .300......	.110	.66	.0726
	2	4—Ribs ea. from $19\frac{1}{2}$ of $\frac{1}{4}$ x $2\frac{1}{2}$ Hot rolled steel. Total wt. 15 lbs.			
2		Shear to length at .0025 ea. Set up .200	.0300	.66	.0198
		Grind 2 corners at .010	.040	.66	.0266
	3	4—Pads each from $4\frac{9}{16}$ of $1\frac{1}{4}$ x $3\frac{1}{2}$ hot rolled steel. Total wt. 24 lbs.			
2		Saw to length at .020 Set up .100	.090	.66	.0594
	4	4—Pads each from $3\frac{3}{4}$ of $\frac{1}{2}$ x $3\frac{1}{8}$ hot rolled steel. Total wt. 8 lbs.			
2		Shear to length at .0025 Set up .200	.0300	.66	.0198
5	1 to 4	—Lay out, assemble and tack weld at 1.600 each. .200 set up	1.620	.75	1.2150
5	1 to 4	—Arc weld complete at 1.700 set up .080	1.708	.75	1.2810
11	1 to 4	—Shot blast at .200 Set up .080	.208	.60	.1248
11	1 to 4	—Paint (primer coat) .100 ea. Set up .080	.108	.60	.0648
		TOTAL LABOR IN A-2 DEPT.	3.974		$2.9234

The final write up is made by the cost control office staff from the data supplied by their shop representatives on form 705, a copy of which is shown in Fig. 13.

The big advantage of the system is that anything out of line comes to light at once and can be investigated while the work is still in progress, whereas under the more conventional systems, such as used by the statistical branch, there is a considerable delay between the work and the record so that it is some time before irregular costs come to light. The adoption of the foregoing method of estimating has proven particularly valuable in its application to the arc welding department, as the extremely rapid advance in both the actual welding procedures and in the development of what might well be termed "Shop Tricks" has made many of yesterday's impossibilities today's accomplishments, and it has been

APPARATUS ______
KEY DRAWINGS ______
ENGINEER IN CHARGE ______
EST. MONTHLY ACTIVITY ______

ESTIMATE No. ______

No. OF SHEETS ______
SHEET No. ______

ORDER No. ______
DATE STARTED ______
DATE FOR COMPLETION ______
No. OF SAMPLES REQ. ______

Form 705

GENERAL										ESTIMATED COST							TOOLS		ACTUAL COST			MATERIAL			
LINE NO.	DRAWING NUMBER	ITEM NO.	DWG. SUB.	STYLE NO.	NAME OF PART	NO. REQ.	OPERATIONS	DEPT. NO.	GROUP NO.	TIME LIMIT SET	EST. HOURS EACH	HOURLY RATE	DIRECT LABOR	MATERIAL	FACTORY EXPENSE	FACTORY COST	TOOL NO.	MACH. NO.	TOTAL	+	—	MATL. AVAIL.	NEW MATL.	REQUISITION NO.	REMARKS

Fig. 13. Estimate sheet.

very difficult for the man on the drawing board to keep abreast of all the improvements.

Every order that goes through the plant has its cost made up, irrespective of whether it is a product for sale, for plant use, or for customer service, by the section devoted to cost recording and referred to earlier.

Educational Activities.—The change from the more or less common form of welding organization, which, like "Topsy", "just grew", began a number of years ago with the decision to send two men to a well known arc welding school. They were to take the arc welding operator's course, to be followed in the one case by an inspector's course and in the other by the engineer's course. The man to follow the engineering phase was the senior time study man in the welding shop for some two years prior to this time, while the one to follow through the inspection side was an unusually intelligent arc welder. The reason for having such men take an operator's course was to enable them to, in turn, teach other men and use standard methods in so doing.

They returned several months later, the one to take up the duties of welding inspector, the other to take charge of all arc welding work, with instructions to survey the plant and make recommendations upon which the future arc welding methods and organization would be based.

One part of his report advised the immediate organization of two arc welding classes; one, through which all persons who did any arc welding must pass, irrespective of previous experience or rated ability; the second one to be for design engineers and leading draughtsmen, with the object of acquainting them, in the most practical manner, with the possibilities in arc welding.

Both were proceeded with, using the two trained men as instructors. The arc welding department was placed on a five day week to clear Saturdays for training. All arc welders were informed that they must qualify by means of the course as first class arc welders, to remain on welding work. The shop did not operate on any form of productive work during school hours, and no wages were paid for time so spent in school work. Men who had been welding for years felt rather keenly on being told they must take a course to hold their jobs, but the objections disappeared when they were informed that, as soon as they could prove their ability by passing the various tests using the prescribed methods, they would receive an A-1 rating with a certificate to that effect. The use of the certificate was extremely helpful in dispelling objections, and the sight of the engraved blanks changed the objections to a spirit of rivalry as to who would be the first to qualify.

In addition to all arc welders, several young men between the ages of 22 and 28 were admitted to the course with the object of at least partially training them to form a reserve staff of arc welders. All of those selected were regularly employed within the welding department, and included operators on spot welders, and helpers for lay out and assembly men, all of whom could easily be replaced when they eventually became regular arc welders.

The second portion of the course was run as an evening school from 7:00 to 9:30 twice each week. A nominal fee was charged, returnable to all attending 90% or more of the sessions. The number of acceptances was limited to the amount of equipment available, at that time 27, consisting of 22 from multiple operator sets and 5 from single operator outfits.

Some doubt as to the willingness of design engineers to return to the plant two evenings a week for six months was expressed by the works management, but this was more than dispelled by the receipt of applications from 75% of the staffs within five days of the announcement, compelling a selective distribution of the registrations between the various divisions.

An improvement in design was noted almost from the start of the course, and it is the expressed opinion of the works management that while it is hardly practical to quote the resulting improvements in terms of dollars and cents, the advantages obtained by the design staff being thoroughly familiar with shop work and practice were enormous. Working drawings immediately showed the results of the school, in that allowances were corrected, welds were not placed in inaccessible locations, less weld metal was used and a greater use made of the bending and rolling equipment.

An apprentice system has been put into effect in our welding department that is similar to the one used to develop mechanics in all other departments of the plant that require skilled help. The first essential for this new trade was a name and we have called it a course in "Arc Welding Fabrication" and the workman as a "Steel Fabricator". It was inaugurated some three and a half years ago and the first two boys are now in the last months of their course, making it possible to evaluate the results being obtained. Both have proven well adapted to the work and are far superior to the class of help posing as mechanics at the employment office. Others have been added as rapidly as the shop could absorb them and so far all seem to be developing rapidly.

The course as lined up is considered as a four-year period, with each year consisting of 52 weeks of 44 hours, or 2288 hours work considered as one year. The apprentice starts to work at an hourly rate of between 30 and 35 per cent of the full mechanic's pay and is increased a minimum of 5 per cent each six months, with larger increases given for superior work. The syllabus now in effect allots the boy's time as follows:

Shearing, laying out, punching, drilling and tapping of structural details	3 to 5 months
As a helper on heavy assembly work	4 to 6 months
Flame cutting of steel plate and structural parts	2 to 4 months
Light sheet metal fabrication, including laying out, cutting, forming and template making	6 to 8 months
Laying out, forming and assembling of light and medium weight plate work	3 to 5 months
Transferred to the drawing office for work as a junior draughtsman	4 to 6 months
Arc welding (includes operators training course)	8 to 10 months

Complete fabrication of light, medium and heavy plate work; during this period he will do everything required to fabricate by arc welding except such work as must be done on machines that have a regular operator .... 10 to 12 months

During his last year an apprentice takes the run of the orders and works as a mechanic except that he receives special supervision and assistance when required.

An arrangement is in effect with the local technical school whereby all apprentices in the plant, including those on the above work, attend the school for one half day or four hours per week and receive instruction in mathematics, up to and including Trigonometry, Draughting and English.

All industrial concerns are aware of the need for a reserve of young trained engineers and of the desirability for absorbing a few each year. Practical training is the greatest need of the newly graduated engineer and to supply this there has been developed a graduate student course that follows somewhat the apprentice system, in that the student is given as wide a variety of work as is possible while taking an actual part in the productive work. This course requires two years, and of this period graduates in mechanical engineering spend four to six months in the arc welding section. During the first two to three weeks they are given the work which comprised that done by the regular engineering staff in the evening classes described earlier. They then join a group engaged in lay out, forming, and assembly work, in which they act as helpers, spending four to six weeks in each of principal lines.

While the training of arc welding operators, of mechanical apprentices for contributory operations, and of young engineers to apply the process, are all a part of the educational work connected with modern weldery operations, they do not complete this phase of the activities. The arc welding supervisor or engineer must advance with, and if possible be ahead of, the progress within his profession. This involves constant effort to become more and still more familiar with both the underlying principles and the latest developments in the field of metals and the means by which they may be joined. He must study, analyze, and apply the result of such work to the solution of his problems and to a profitable extension of the process. Active membership in organizations devoted to welding and allied subjects, combined with a studious reading of the leading journals featuring welding and associated matters, will do much to keep the specialist well informed of current developments. The acquisition and use of books written by leading authorities on these subjects and the gradual building up of a complete welding library will further assist him to acquire additional useful knowledge.

SECTION VIII

CONTAINERS

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SECTION VIII
CONTAINERS

Chapter I—Arc Welded Oil Well Casing Provides Substantial Savings

By G. M. STEARNS,
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It is an established and indisputable fact that in the drilling and producing of oil wells, one or more strings of casing must be installed in the bore of the well. Some of the casing run into wells during the progress of drilling operations may be only temporary, that is, it may be pulled from the well after the well has been drilled to the desired depth. But on the other hand, all wells which are found to be commercial producers of oil must be equipped with a certain amount of casing as permanent equipment. This casing must withstand the subsurface pressures, mechanically applied pressures, corrosive action of fluids, tensile stresses, compressive stresses, and other natural and artificial agencies with which it may come in contact in a well. From the following discussion of the reasons for running casing it will be seen why, and to what extent, the casing must resist the above-mentioned forces.

In practically all localities where oil wells are drilled, there are surface water supplies, and shallow water sands which an oil producer must protect from pollution by fluid from deeper salt water sands and oil producing zones. Failure to prevent such pollution leaves the operator liable to costly damage suits which have been known to result in bankruptcy of financially strong operators. So this condition requires the oil producing company to install what is known as their surface string of casing. This surface casing is generally set with the bottom just below any fresh water supply which may possibly be used for domestic or public purposes, and such casing is usually encased in cement from top to bottom. This surface casing should naturally be kept leak-proof, or else its primary purpose is defeated. Leaks may be caused principally by corrosion, bad joints, and wear occasioned by drilling through it in finishing the drilling of the well. In some cases this string of casing answers also the purpose of shutting off caving formations which would otherwise fall into the well and hamper drilling progress.

Intermediate Casing Strings.—In many fields it is necessary to install in a well one or more intermediate casing strings. These intermediate strings are run into wells for different purposes, depending upon the conditions encountered in any particular locality. Some of the reasons for installing intermediate strings are:

(1) To exclude a high-pressure or high-volume water sand which fills the hole so much as to hinder drilling progress to greater depth;

(2) To shut off high-pressure gas (where oil is sought, or where the gas is unsuitable for commercial usage);

(3) To protect the inner string of casing, to be run later, from action of strongly corrosive fluids which are sometimes encountered at some intermediate depth in wells. Since such corrosion must penetrate the outer intermediate string of casing before coming in contact with the inside string of pipe, the period of time before the productive value of a well would be damaged from this source could be doubled by the use of this intermediate string of pipe. In some special cases where wells are drilled to great depths, more than one intermediate string of casing is used.

All wells are equipped with what is known as the oil string of casing. Modern operating practice is to encase at least the lower part of this string of casing in cement, generally up into the next larger and shorter string of pipe. It is important that this casing string be:

(1) Leak-proof under any pressures that may be encountered;

(2) Of high enough tensile strength that in running to the setting depths, the upper joints will not part (a safety factor of 2 is generally allowed on this item);

(3) Resistant to collapse, since enormous pressures act against the pipe at greater depths. However, the pressure outside of the pipe is counteracted by fluid pressure inside the pipe until the cement has hardened around the pipe which increases the collapse resistance of the string.

New Technique Adopted.—Until recently the general practice among oil operators has been to use threaded and coupled casing with some exceptions in the case of "stovepipe" surface casing of comparatively light weight and short length. Within the last year, however, the company with which the writer is connected, along with other oil companies, welding concerns, and pipe manufacturers, have developed a new technique in the installation of casing which involves arc welding the joints of casing on the derrick floor as the casing is run into the well. This new practice is now being adopted by us because of:

(1) The substantial saving that can be realized in the total cost of the pipe strings, as will be analyzed in detail in this paper;

(2) Increased joint strength which makes possible the safe running of longer strings of pipe and results in less possibility of loss of pipe in the hole due to failure of the string when under stress;

(3) Less possibility of leaks under high pressure conditions;

(4) Possibility of more complete recovery of pipe on abandoned wells, since with butt-welded joints there are no couplings or similar projections on the outer circumference of the pipe to hinder pulling the string.

Since these advantages are of vital consequence, there is little doubt that the arc welding of casing will within a short time become a general practice and replace the former method of running screw pipe. Even in wells where the casing is to be only temporarily installed, the development of portable cutting and bevelling machines may result in practically universal use of welded casing in wells.

Development of Technique for Running Arc Welded Casing.—The procedure followed in developing this new technique of running casing may be outlined as follows:

(1) Tests and studies to arrive at the proper grade of casing, proper size and strength of electrode, proper welding procedure, and proper type of welded joint to best meet our needs.

(2) Development of tools to use in properly running the new type of casing.

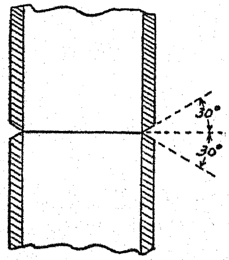
(3) Training of personnel—welders, drilling crews and casing crews—in the correct procedure for actual running of the casing.

Preliminary Tests and Studies.—As to the grade of casing required for this sort of welding operation, it was found that the carbon content of the steel in the casing is the controlling factor in the weldability of the casing. The pipe manufacturers furnish us casing of an average carbon content of 0.25% and not to exceed 0.35%. Since casing of this carbon content is available on the market, this part of the problem is easily solved.

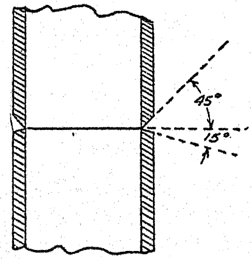
In choosing the size of electrode, the largest size possible to use, without resulting in the molten weld metal running down the side of the pipe, was used. It was found in the welding of ordinary casing, that is, of the usual wall thickness, with a butt joint, that a $\frac{3}{16}''$ electrode was the largest that could be used successfully. With bell-and-spigot and slip-joint pipe the size of electrode used is limited only by the thickness of the top of the bell or collar which forms the flat surface down against which the welder deposits his weld. As to the strength of electrode used, this is governed by the manufacturer's minimum guaranteed strength of the casing. The strength of electrode is kept equal to or slightly above the strength of the casing. That is, with casing of a minimum guaranteed tensile strength of 90,000 lbs. per sq. inch, an electrode of a strength of not less than 90,000 lbs. per sq. inch nor more than 100,000 lbs. per sq. inch should be used. The strength of electrode should not exceed the strength of the pipe by an appreciable amount because the higher strength electrodes produce a less ductile weld.

In deciding which type of joint to use, (See Fig. 1), we took advantage of the results of tests made by some of the pipe manufacturers and an oil company to determine the relative strengths of the different types of joint. These tests were full joint pull-out tests, and showed that butt-joint and bell-and-spigot joints gave a much higher joint efficiency than threaded and coupled joints. From Tables 1 and 2 it can be seen that joint efficiencies ranging from 84.6% to 100% were obtained with the straight butt-joint, while efficiencies ranging from 93.4% to 100% were obtained with the double bell butt-joint with chill ring. The greater joint efficiency of the double bell butt-joint was probably due to obtaining more complete penetration with the chill ring as backing. Other tests by a pipe manufacturer on bell-and-spigot joints gave joint efficiencies ranging from 90% to 100%. Since the straight butt-joint shows practically as much strength as the two other types

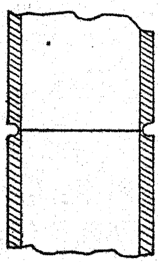
of joint, and costs less in buying the pipe, it was selected by us to use for the welded strings. The slip-joint was disregarded because that it gave little additional strength as compared to the threaded and coupled joint and also resulted in little saving over the threaded joint.



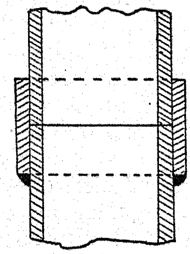
Symmetrical Vee Butt Joint



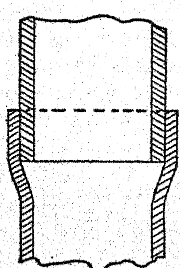
Asymmetrical Vee Butt Joint



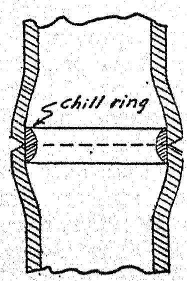
U-Bevel Butt Joint



Slip Joint
(Lower side of coupling is welded by pipe manufacturer)



Bell-and-Spigot Joint



Double-Bell Joint with Chill Ring

Fig. 1. Various types of joints used in arc welding oil well casing.

TABLE I—SUMMARY OF PULL-OUT TESTS MADE ON A. O. SMITH CASING PIPE WITH GIRTH WELDS

TESTED BY A. O. SMITH CORP. IN 1000 TON HYDRAULIC PRESS—U-BEVEL BUTT JOINT

Pipe No.	Nom. Size of Pipe Dia. x Wall	Wt. Per Ft.	Tensile Strength of Stl. in Pipe	Load on Joint— Pounds	Stress Developed— Wall of Pipe	Setting Depth F.S./2	Failure in Test	Joint Efficiency Percent
A-1	10¾" x .400"	45.5	94,600 psi	1,190,000	88,800 psi	13,100 ft.	Broke in Girth Joint in Weld & Edge of Weld	93.9
A-2	10¾" x .400"	45.5	94,600	1,070,000	80,000	11,780	Broke in Top Hd. Weld and Stock	84.6
A-3	10¾" x .400"	45.5	94,600	1,255,000	93,600	13,800	Broke in Girth Joint in Weld	99.0
C-7	13⅜" x .380"	54.5	86,200	1,283,000	82,000	11,750	Broke in Girth Joint 100% in Weld	95.1
C-8	13⅜" x .380"	54.5	86,200	1,210,000	77,300	11,100	Broke in Girth Joint Weld & Stock	89.6
C-9	13⅜" x .380"	54.5	86,200	1,375,000	87,700	12,600	Broke in Girth Joint Edge of Weld & Weld	100.

CHEMICAL ANALYSIS

	C.	Mn.	P.	S.	Si.
PIPE "A"	.27	1.48	.016	.018	.06
PIPE "C"	.22	1.45	.013	.018	.11

TABLE II—SUMMARY OF PULL-OUT TESTS MADE ON A. O. SMITH CASING PIPE WITH GIRTH WELDS

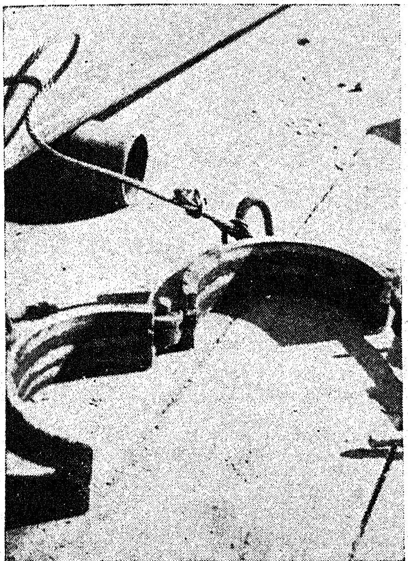
TESTED BY A. O. SMITH CORP. IN 1000 TON HYDRAULIC PRESS—DOUBLE BELL JOINT

Pipe No.	Nom. Size of Pipe Dia. x Wall	Wt. Per Ft.	Tensile Strength of Stl. in Pipe	Load on Joint—Pounds	Stress Developed—Wall of Pipe	Setting Depth F.S./2	Failure in Test	Joint Efficiency Percent
B-4	10¾" x .400"	45.5	89,000 psi	1,155,000	84,500 psi	12,700 ft.	Broke in Girth Joint in Weld	94.9
B-5	10¾" x .400"	45.5	89,000	1,245,000	91,000	13,700	Broke in Girth Joint Edge of Weld & Weld	97.8
B-6	10¾" x .400"	45.5	89,000	1,269,000	92,600	13,950	Broke in Girth Joint Weld & Edge of Weld	100.
D-10	13⅜" x .380"	54.5	94,800	1,389,000	88,500	12,720	Broke in Girth Joint Edge of Weld	93.4
D-11	13⅜" x .380"	54.5	94,800	1,467,000	91,600	13,420	Broke in Girth Joint in Weld	96.6
D-12	13⅜" x .380"	54.5	94,800	1,548,000	96,700	14,180	Broke in Girth Joint in Weld & Edge of Weld	100.

CHEMICAL ANALYSIS

	C.	Mn.	P.	S.	Si.
PIPE "B"	.28	1.35	.016	.020	.06
PIPE "D"	.30	1.53	.015	.019	.10

On our first few casing strings the joints were bevelled with a 30° bevel on each end, leaving a 60° symmetrical opening in which to deposit the weld metal. We later tried a string of casing with a 15° bevel on one end and a 45° bevel on the other end of each joint, thinking that this would result in more ease of welding because with the 15° bevel up and the 45° bevel down the weld more nearly approaches the position of a fillet weld, which theoretically results in more ease of welding. However, actual use of this 15°—45° bevel did not prove to be of any special advantage to the welding operators. In fact these particular operators did not like it as well as a 30°—30° bevel because the 15°—45° bevel made it more difficult to obtain thorough penetration. Further experience and investigation has taught us that the U-bevel makes possible a little greater welding speed and more complete penetration.



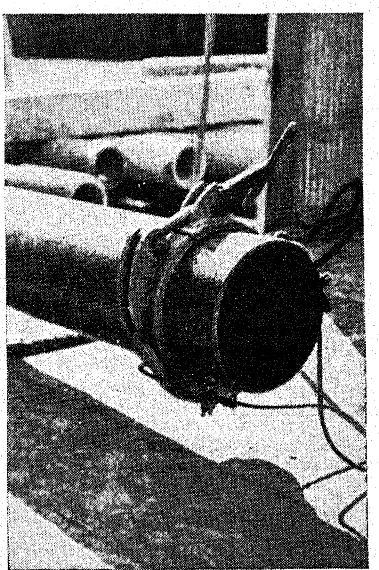


Fig. 2. Left—Pick-up clamp for picking up each joint of casing and lifting into vertical position in derrick. Fig. 3. Right—Clamp tightened on joint of casing.

Special Tools Used in Running Butt Welded Casing.—The running of butt welded casing required a number of tools which are different to the tools commonly used in running threaded and coupled casing. The first operation which required a different tool was the picking up of each joint from the rig walk and lifting it into a vertical position preparatory to aligning for welding. In running threaded and coupled casing, each joint is picked up merely with a hemp rope noose which is slipped on beneath the coupling. This method would not be safe with the plain end pipe.

Figs. 2 and 3 show the clamps used to pick up the plain end casing. Note in Fig. 2 that the clamps have two dark rings visible around

their inside circumference. These rings are ridges of babbit that are poured into grooves cut on the inside of the steel clamps. This was done as an extra safety precaution to prevent the clamps from slipping off when pulling the joint up into the derrick.

Another new tool that was devised for the running of the plain end butt-welded casing was the clamps for lining up each joint with the joint just below it. Figs. 4, 5, and 6 show different views of the use of these clamps. These clamps are about 42″ in length and are hinged on one side with toggle screws on the opposite side. They are hung on a line which runs over a pulley up in the derrick and has a counterweight on the other end to balance the weight of the clamps. The casing crew can quickly place them around the joint to be welded and tighten them to hold the pipe straight until the welders tack-weld the pipe sufficiently to hold the upper joint in position. The clamps are then removed and hang in the derrick until needed to align the next joint.

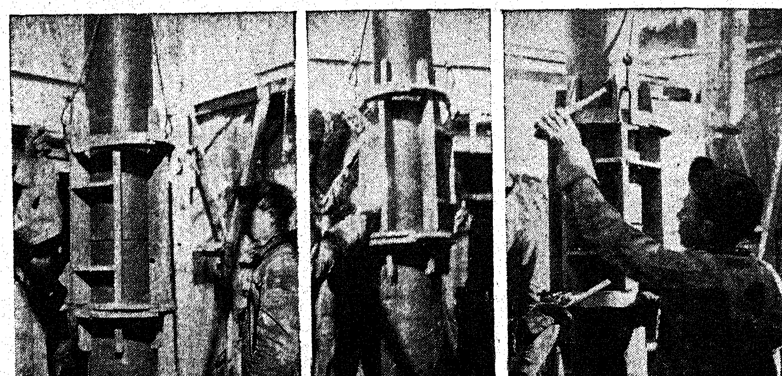


Fig. 4. Left—Aligning clamp in place. Fig. 5. Center—Tack welding joint with aligning clamp in place. Fig. 6. Right—Removing aligning clamp after tacking.

An automatic trip casing spider is better than the ordinary casing spider to use on the derrick floor for holding the part of the casing already in the well, since the automatic spider is not so apt to allow the dropping of pipe before reaching the desired setting depth. The automatic spider can be set merely by tripping one lever, while each slip must be placed separately around the pipe when using the ordinary spider. Because of the fact that there is no coupling at the top of each joint of plain end casing, the ordinary casing elevators to use in letting the pipe into the well could not be used. It was found necessary for this reason to use slip-type elevators as shown in Fig. 7. Although the slip-type elevators are more cumbersome and slower of operation than ordinary elevators, we know of no other way to insure the holding of the casing. Extra care is taken to keep the teeth sharp on the slips of the casing spiders and elevators.

Training of Personnel.—We experienced very little difficulty in training the crews to run the welded casing. Our welding has been

done by welders who have made this type of welding a specialty and have more or less developed along with the new technique. Their supervisor has taken the responsibility of training the welders and has tested their welds of this type of joint in tensile machines. So the problem of training the welders has not been ours. Our experience with the welding has been very satisfactory.

In the running of practically all of our welded casing strings to date we have had at least some men in the drilling and casing crews who are inexperienced in the running of welded casing. At first, this slows down the progress of the work somewhat, but only a very short time is necessary for the crews to become accustomed to the new procedure. By the time a man has worked on one such job, he is adapted to the new routine of the work. The duties assigned to the drilling and casing crews are as follows: One man to roll pipe from the casing rack on to the walk; another man to put on the pick-up clamps and guide each joint into the derrick; two men to put on and take off the alignment clamps and hammer the welds to remove the slag after each of the first two beads; another man up in the derrick to remove the pick-up clamps from the top of each joint and attach the elevators; and the driller to operate the machinery controls and direct the crew.

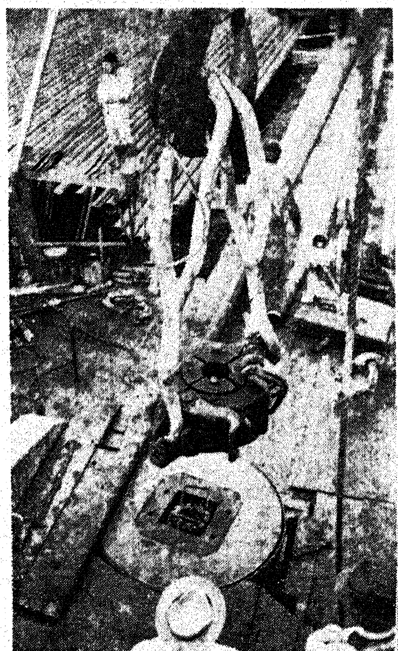
Complete Data on a Typical Job.—The data tabulated below is an actual report from the running of a string of casing into one of our wells in the Letsch Pool of Russell County, Kansas:

Description of casing: 7″ O.D. 22 lb., plain end. (Carbon content—0.25%, Manganese—0.80%.)
Kind of bevel: Each joint with 15° on top and 45° on the bottom.
Total joints of casing run into well.......... 69
Total circumferential welds (including shoe and nipple)..... 71
Total footage of casing string..........2933′
Number of beads at each joint.......... 3
Total elapsed time per joint (overall): 8 Min. 10 Sec.

(Note: Welding time given below is from stop-watch timing of the period of arc contact for each step in individual welds. The remainder of the total time was consumed in cooling of the weld before lowering into the drilling fluid, filling casing with fluid, hammering welds, picking up and lining up joints and other auxiliary operations.)

Ave. actual welding time—Tack weld..........29 Sec.
Ave. actual welding time—1st bead..........46 Sec.
Ave. actual welding time—2nd bead..........71 Sec.
Ave. actual welding time—3rd bead..........72 Sec.
Ave. actual welding time—Total per joint..........3 Min. 38 Sec.
Total lbs. of welding rods used..........52 Lbs.
Ave. lbs. of weld metal per joint..........0.73 Lbs.
Tensile strength of welding rod, lbs./sq. in..........100,000 Lbs.
Total actual time generators were delivering power..........4 Hrs. 18 Min.
Ave. amperage delivered..........175
Ave. voltage of generator..........30
Power output of two generators for entire job..........45.15 KWH

Method.—Aligning clamps placed on each joint. Joint tack welded at four points. Aligning clamps taken off. First bead welded on. (See Fig. 8). Slag chipped off manually with ball-and-peen hammers and wire brushes. Second bead welded on. Slag chipped off as before. Third bead welded on. Weld allowed to cool about 1 minute 45 seconds before placing the weld in tension by lifting the pipe to remove the slips from the casing spider in order to lower the pipe into the well. An additional 15 seconds elapsed before each weld came in contact with the drilling fluid, which made a total of about 2 minutes cooling time for each weld before quenching in the drilling fluid. Tests showed this to be ample cooling time to prevent embrittlement and consequent weakening of the weld and adjacent steel in the pipe which might occur if the welded joint were immediately lowered into the fluid-filled hole.



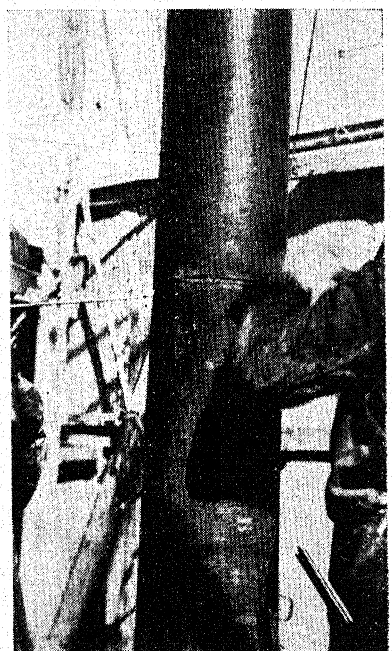


Fig. 7. Left—Slip-type elevators used for plain-end casing. Fig. 8. Right—Two arc welders applying first bead.

It is doubtful if the use of the ball-and-peen hammers and wire brushes for slag removal is an effective method. We are considering the use of an electric hammer for this purpose, since such instrument would possibly be more effective in removing the slag along the edges of the weld.

Cost Analysis.—Since the casing job described above is quite typical of our method of running a butt-weld casing string in Western Kansas, it will be used as a basis from which to calculate the saving

to the oil operating company which installs this type of casing string rather than the generally-used threaded and coupled string.

There are two situations which should be considered separately in calculating this saving. First, there is the oil company which has its own welding equipment and hires operators at a certain rate per hour or on salary. Such a company should necessarily have a large amount of welding work in a particular locality to justify having its own machines and operators. Second, there is the oil company which hires a welding concern with machines and operators to do each individual job as it arises. Our company falls within this latter class. Since there may be oil companies in each class an analysis of the cost for each situation is worked out in this paper.

The running of welded casing consumes only slightly more time than the running of threaded and coupled casing; but on the other hand, the installation of a welded string requires a smaller crew, aside from the welders, than for running threaded and coupled casing. So in calculating the saving this additional running time is neglected since it should be offset by the smaller crew. Anyway, as time goes on, the running time of welded casing can possibly be made to at least equal the running time for threaded casing. Thus, the saving due to the use of welded casing resolves itself into the difference between the cost of plain end casing and the cost of threaded casing minus the cost of welding.

1. *Saving to the oil company which does its own welding:

Cost of 2933′ of 7″ O.D., 22 lb., threaded and coupled casing @ $105.53 per 100 ft.	$3,095.19
Cost of 2933′ of 7″ O.D., 22 lb., plain end casing for butt welding @ $89.70 per 100 ft.	2,630.90
Saving on Cost of Pipe	$ 464.29
Cost of labor in welding:	
3 welders (10 hrs. @ $1.16 ea. per hour)	$ 34.80
25% overhead on labor	8.70
Cost of weld metal (52 lbs. @ $0.16)	8.32
Cost of power (45.15 KWH @ $0.06)	2.71
Mileage on welding trucks to and from well location (30 miles ea. @ $0.05 ea. per mile)	3.00
Total Welding Cost	57.53
Total Net Saving	$ 406.76
Net saving per joint of casing	$ 5.90
Net saving per foot of casing	$ 0.139

2. *Saving to the oil company which hires job welders:

Saving on cost of pipe (same as above)	$ 464.29
Less cost of welding (10 hrs. @ $9.00 per hr.)	90.00
Total Net Saving	$ 374.29
Net saving per joint of casing	$ 5.43
Net saving per foot of casing	$ 0.1276

*NOTE: Cost figures do not include moving equipment and materials, (except arcwelding machines), to the job. They cover only the cost of the casing and the actual work of welding the joints, plus mileage on welding trucks.

Of course, the saving per foot of casing would be influenced by the average length of casing joints. To realize the maximum saving the oil producer should install casing made up of joints as long as practicable, since longer joints mean fewer welds. Casing joint lengths can hardly exceed 40 feet, however, because a longer joint can not be easily pulled up into an ordinary derrick.

Cost analyses calculated from the running of about 1100 feet of 10¾", 40.5 lb., casing give the following savings:

1. If oil company does its own welding:
   Net saving per 30-foot casing joint........................$7.44
   Net saving per foot of casing........................$0.2479
2. If oil company hires job welder:
   Net saving per 30-foot casing joint........................$6.74
   Net saving per foot of casing........................$0.2247

The greater net saving per foot on the 10¾" pipe as compared to the 7" pipe is due to the fact that mill prices for plain end pipe are 15% less than mill prices for threaded and coupled pipe regardless of pipe size. Thus, the "dollar-and-cents" saving in pipe purchase price becomes higher for larger sizes of casing and is in direct proportion to the price of threaded and coupled pipe, whereas, the cost of welding does not increase proportionately.

Estimate of Total Saving to Oil Producing Industry if Arc Welding of Casing Were Universally Adopted.—Due to the fact that casing programs vary so radically from field to field, it is practically impossible to arrive at an intelligent estimate of the amount and sizes of casing installed in oil wells in the United States during any particular period. It is apparent, however, that an enormous saving can be realized by the oil producing industry through the use of welded casing strings. In Rice, Barton, Russell and Ellsworth counties in Kansas there were 1037 producing oil wells completed during 1937. The most generally used casing program in these counties are about 350′ of 10¾" casing and about 3200′ of 7" casing. In Ellis county, where the most generally used casing program is about 1100′ of 10¾" casing and 3400′ of 7" casing, there were 194 wells completed during 1937. In these five counties, which represent only 1231 wells out of 23,600 completed in the United States for the year, the saving by use of welded casing to replace threaded and coupled casing is estimated as follows:*

Saving on 10¾" string (350′ @ $0.2247)	$ 78.65
Saving on 7" string (3200′ @ $0.1276)	408.32
Saving per well (Rice, Barton, Russell, Ellsworth)	$486.97
Total saving for four counties (1037 x $486.97)	$504,988.00
Saving on 10¾" string (1100′ @ $0.2247)	$247.17
Saving on 7" string (3400′ @ $0.1276)	433.84
Saving per well (Ellis County)	$681.01
Total saving for Ellis Co. (194 x $681.01)	$132,116.00
Total saving for the five counties on oil wells completed during 1937	$637,104.00

*Since it is expected that most companies will hire job welders, the saving is calculated on that basis.

No attempt will be made to estimate the total saving for all oil wells completed in the United States during last year, but it is interesting to note that this estimated saving of approximately $637,000.00, is for only 5% of the producing oil wells completed in this country last year.

Conclusion.—Because of the two outstanding advantages—increased joint strength and economic saving—there should be no reason why oil producers will not soon adopt the use of welded casing strings as standard practice. There are other incidental advantages which might lend some favor to welded casing. There is the possibility of reducing the clearance between casing strings, which would mean a further saving in pipe costs. Welded casing should be more easily recoverable from abandoned wells than casing with the projecting couplings.

There is an opportunity for intensive study on this subject, and many new advancements will possibly be made in the near future.

Chapter II—Welding as Applied to Thimble Tube and Watertube Boilers

By EDWARD FRANK SPANNER,
Inventor and designer of boilers described and managing director, Messrs. Spanner Thimble Tube Boilers, Ltd., London, England.

Foreword.—The following paper has been submitted because the various designs dealt with have been rendered possible only by the extensive adoption of electric welding as the basic method of fabrication.

No units of the types described have yet been produced in America, but successful examples have recently been built and installed in Great Britain and in certain merchant vessels for Continental owners.

The designs include a sequence of novel ideas as to constructional design and arrangement of the heat transfer surfaces. These are protected by patents or patent applications in Great Britain and America.

In very many practical applications "Spiralflo" and "Steddyflo" units are concerned with the extraction of heat from large volumes of gas of low specific heat and moderate temperature—often as low as 450 degrees Fahr., this heat being transferred directly to the water to be heated or converted to steam. In such difficult circumstances it is essential to obtain maximum service from every ounce of steel material incorporated in the construction.

Electric welding alone has made it possible to bring "Spiralflo" and "Steddyflo" boilers and water heaters into successful economic existence.

Boilers and Water Heaters for Waste Heat Recovery.—Waste heat recovery units must be of relatively small dimensions, convenient for installation, light in weight, simple in general design, reliable in service, reasonably easy to inspect or dismantle, and, above all, very moderate in price.

Generally, users of diesel engines refuse to consider the possibilities of securing higher overall efficiency from their plant by the installation of waste heat units unless the first cost of these units can be recovered in a year's working.

This fact necessitates great economy in design, and is fundamentally of the greatest commercial importance.

Next in importance comes reliability in service. The unit must be robust in construction, easily maintained, clean and efficient in heat transfer, and not likely to give trouble through leakage or fouling on either the gas or water sides of the heating surfaces.

Diesel engine gas is never entirely clean and to ensure satisfactory service waste heat units must provide ready access to the gas sides of the heating surfaces. Similarly, unless the heat recovery unit is to be used in a closed circuit, or with a water supply which is treated to free the system from fear of scale deposit, the water side of the heating surfaces must be easily accessible.

When investigating the economic possibilities of waste heat recovery, the keen user will take into account the first and maintenance cost of all supplementary items required as the result of the introduction of waste heat recovery plant. In doing so he will find that small dimensions, light weight, simple design and ease of installation are interdependent qualities of considerable importance in enabling expenses to be kept down.

Certain credits will also be noted—particularly the fact that a well-designed waste heat unit serves not only to recover a large proportion of heat from the waste gases, but also effectively to silence the exhaust.

Firetubes v. Watertubes.—Before proceeding to describe the constructional features of welded waste heat boilers and water heaters, a short reference might well be made to the principles of design underlying the development of "Spiralflo" thimble tube units.

Heat transfer from a supply of hot gas to water contained in a pressure vessel is dependent upon break-up of the supply of hot gas so that the maximum number of individual particles of gas are brought intimately into touch with the steel surfaces forming the water boundaries of the pressure vessel.

This break-up can be effected in a variety of ways, the two most widely followed being either:

(1) By subdividing the supply of hot gas into a large number of small individual streams each surrounded by a water-cooled boundary, or

(2) By introducing an extensive system of water-cooled surfaces lying athwart the main stream of hot gas.

The former covers all designs of "firetube" boilers or water heaters, the latter all designs of "watertube" boilers or water heaters.

The main physical difference between these two generic systems for effecting heat transfer may be stated as follows:

In firetube designs the flow of individual streams of hot gas is substantially parallel to the walls of the firetubes. Heat must therefore be transferred from hot gas to water-cooled surfaces which are lying in planes parallel to the lines of motion of the hot gas streams.

In watertube boilers, especially those of the design described in this paper, flow of the main stream of hot gas is substantially at right angles to the walls of the watertubes. Heat has thus to be transferred from hot gas to water-cooled surfaces which are lying directly across the line of motion of the hot gas stream.

Bearing in mind the low conductivity of gases and the difficulty of bringing the "core" of a cylinder of gas travelling through a tube into contact with the wall of that tube, and visualizing also the intensely turbulent flow which must occur around the surfaces of watertubes lying athwart the direction of flow of a stream of hot gas, it can readily be understood why it is that modern experimental research has been able conclusively to prove that under similar conditions as regards temperature differentials, and volumetric gas speeds, the efficiency of watertube heating surface as provided in the designs here discussed is between 50% and 75% greater than that of firetube heating surface.

Some Notes on Thimble Tubes.—Thimble tubes are essentially water tubes in so far as concerns their method of functioning for recovering heat from a stream of hot gas.

In their practical application, they differ from plain water tubes in certain important geometrical, constructional and operational points:

(1) They are much more convenient than plain water tubes for tubing a cylindrical gas passage. Thimble tube nests include a very much larger area of effective water tube heating surface than can possibly be included within a like diameter of any other commercially practicable system of water tubes.

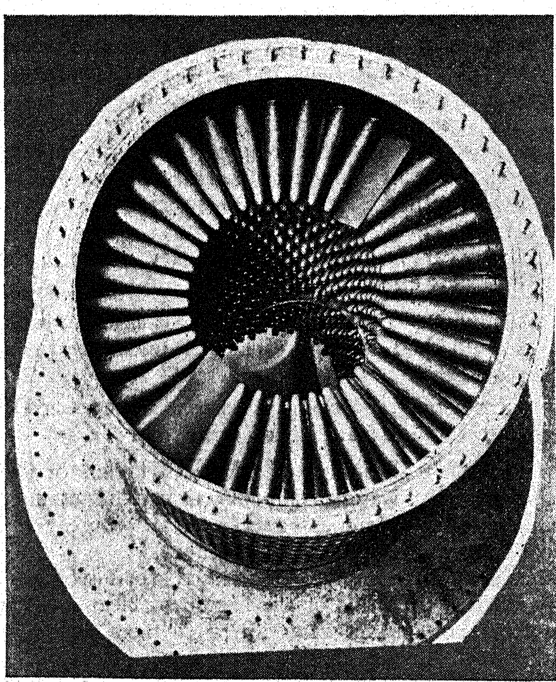


Fig. 1. Thimble tube and tube nests.

(2) They are free from "tube end" troubles. Being free at the closed end and held only by thorough expanding and bell-mouthing at the open water end, violent fluctuations of temperature within the tube nest do not affect the tightness of the tube in the tube plate. Further, there can be no reaction tending to force the tube back through the tube plate such as occurs, due to expansion, with either firetubes or water tubes expanded into tube plates at both ends. As a consequence these direct-fired boilers are very flexible in service and stand forcing well.

(3) Although they would appear to suffer from the fact that there is no "through" passage available to ensure free water circulation, it is found in practice that a thimble tube provides a rapid

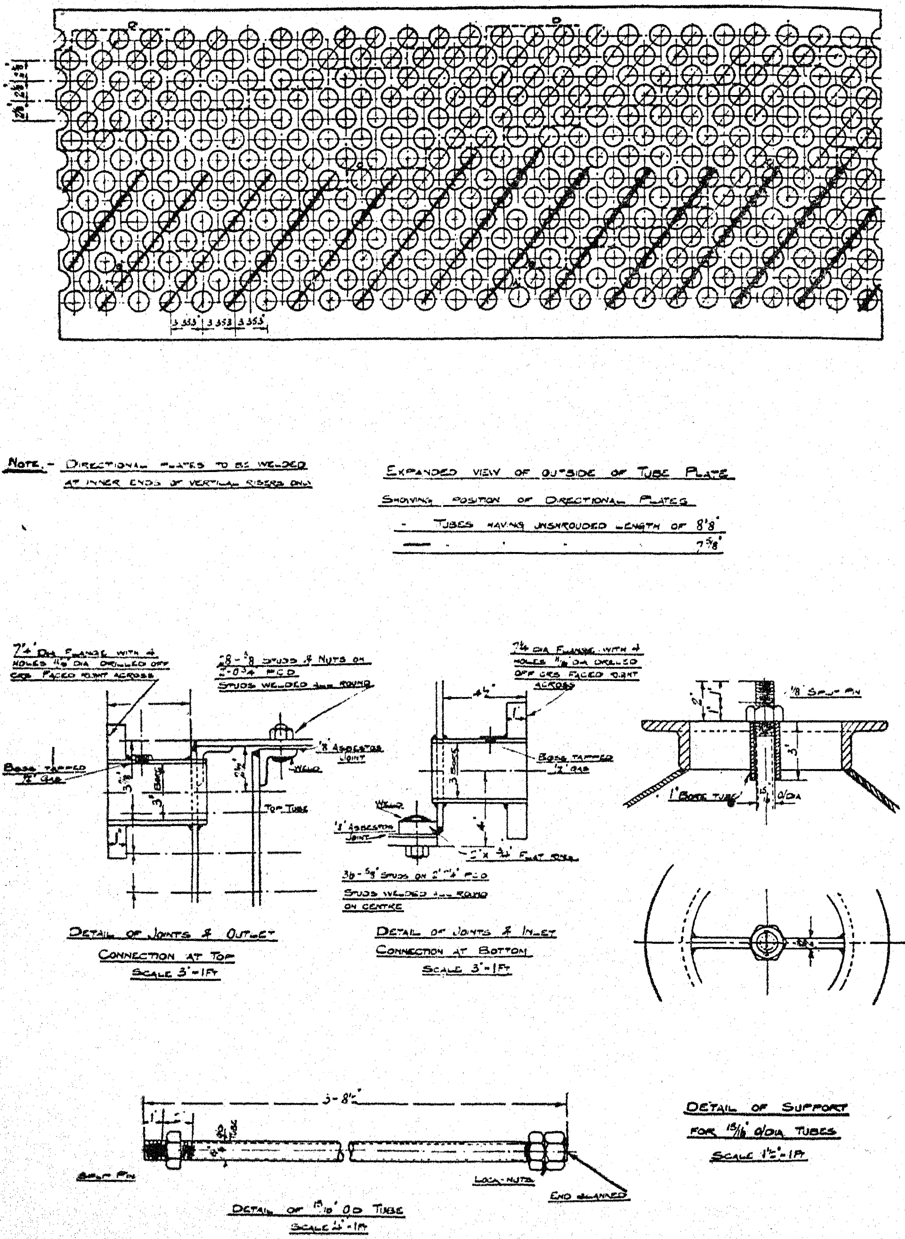


Fig. 2. Typical design of water heater and steam boiler. See also pages 816b and 816c.

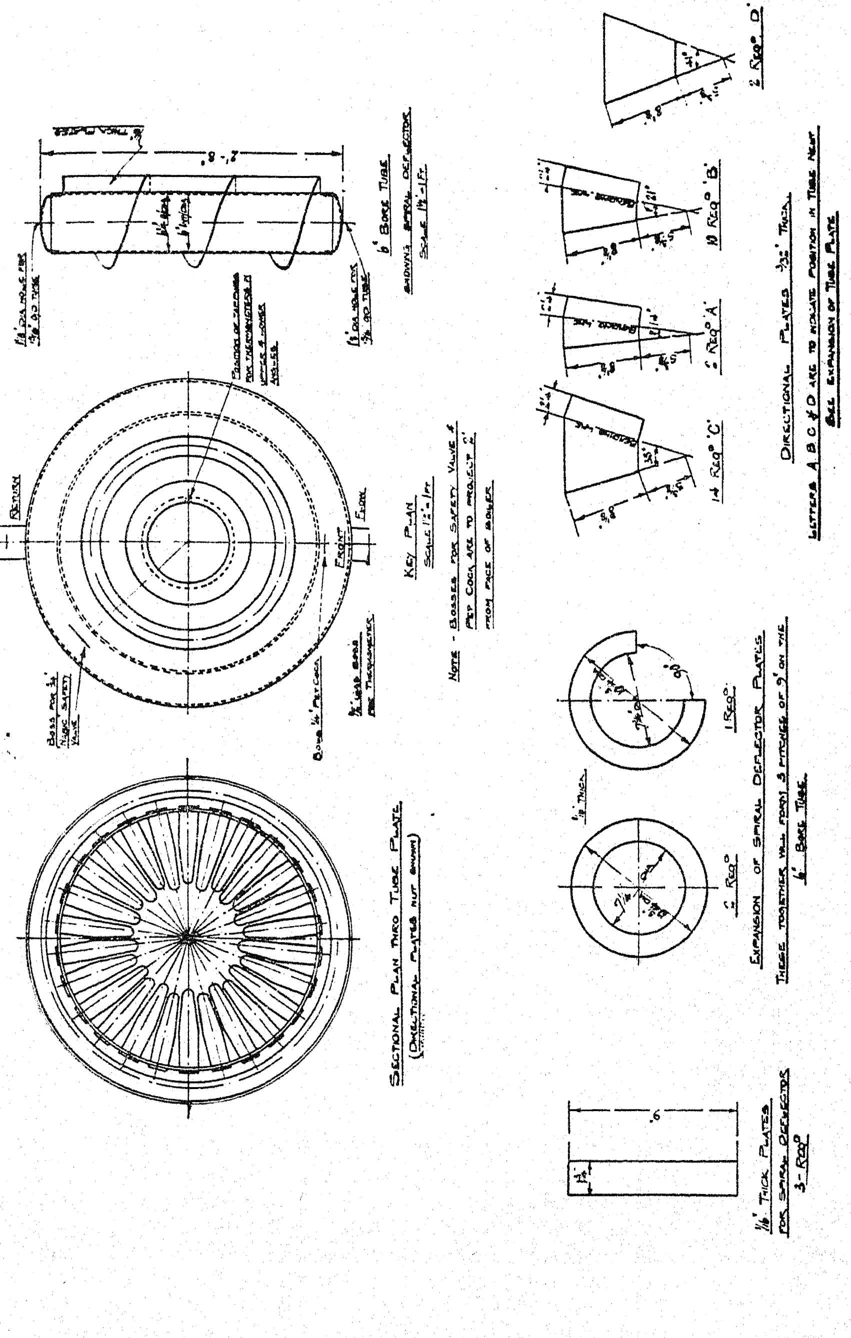
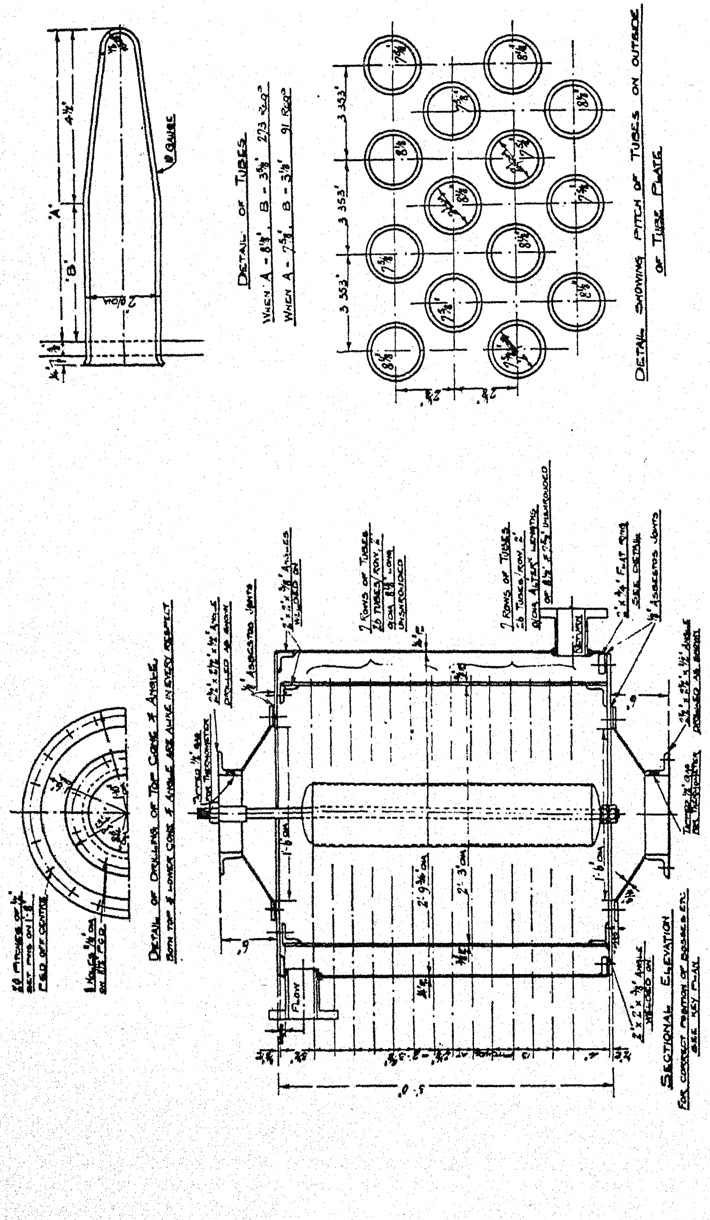


Fig. 2. Typical design of water heater and steam boiler. See also pages 816a and 816c.



SCALE 1½" = 1 FT.

Fig. 2. Typical design of water heater and steam boiler. See also pages 816a and 816b.

flow of water into and out from the tube by reason of simple thermo-dynamic action resulting from the sharp taper of the tube end.

Treated water should be used, or else care taken frequently to clean out the boiler to prevent scale accumulation in the thimble tubes.

(4) One drawback to thimble tube heating surface is that thimble tubes are very expensive to produce, so that considerable ingenuity in design is necessary to make them an economic proposition for other than units of comparatively small size, or for units in which very rapid fluctuations of demand require a tube nest which can stand wide variations of heat input without fear of strain on the tube end connections.

Thimble Tubes and Tube Nests.—Fig. 1 shows photograph of thimble tube and tube nests.

Particular attention is drawn to:

(1) The "family" design of the thimble tubes, whereby all tubes of a given family have entirely similar tube end profiles. This eases the problems of manufacture and maintenance, and gives a very much improved "combing" pattern in the tube nest, the clearance between the tapered tube ends being closer than is otherwise obtainable.

(2) The inherent production of a spiral path for the gases up through the tube nest. This spiral flow can be accentuated and made more positive by the introduction of divisional plates as shown in Fig. 1.

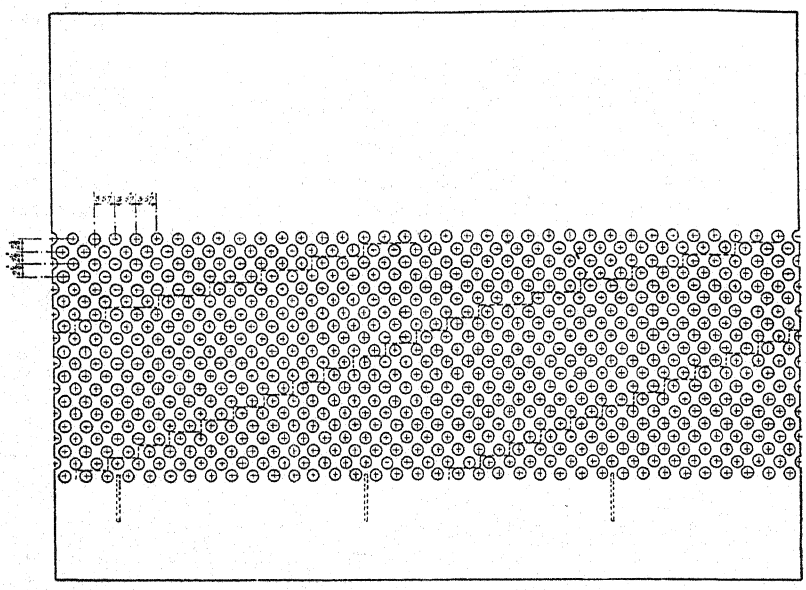
(3) The general character of the spiral deflectors fitted in the centre of the tube nests and arranged to provide control of the gas flow, as shown in Fig. 2.

SPIRALFLO WASTE HEAT WATER HEATERS & STEAM BOILERS FOR SMALL DIESEL ENGINES.

Drawing Fig. 2 shows a typical modern design of "Spiralflo" water heater and steam boiler installed for heat recovery from the exhausts of small diesel engines. It is a vertical unit, one of two fitted to a pair of vis-a-vis diesel engines each of 350 B.H.P. by Messrs. Brush Electrical Engineering Co., Ltd., at a Metropolitan Water Board Power Station in England. In these units the gas passes through a SPIRALFLO thimble tube nest in which stepped spiral divisional plates are fitted at opposite pitch to that of the spiral formed by the thimble tubes.

The drawing shows the character of the welded construction, and confirms that the design is one in which welding has made it possible to reduce the size and weight of the unit to the maximum possible degree. These units were put into service in the latter part of 1937.

It might here be pointed out that from the point of view of maximum economy, waste gas water heaters are inherently more efficient than waste gas units used for steam raising. Further, the technical requirements of insurance authorities are less onerous for water heaters than for units to be used for steam raising, particularly in respect to the mountings required.



EXPANSION OF TUBE PLATE (EXTERNALLY)

PRESSURE PARTS OF SPIRALFLO WASTE HEAT BOILER.

FOR

MESSRS CROSSLEY PREMIER ENGINES LTD.

WORKING PRESSURE 120 LBS/□"

SURVEY: NATIONAL BOILER & GENERAL INSURANCE Co LTD

SCALE 1"&6" = 1FT.

Fig. 3. Boiler installed for raising steam at working pressure of 120 lbs. per sq. in.
See also page 817b.

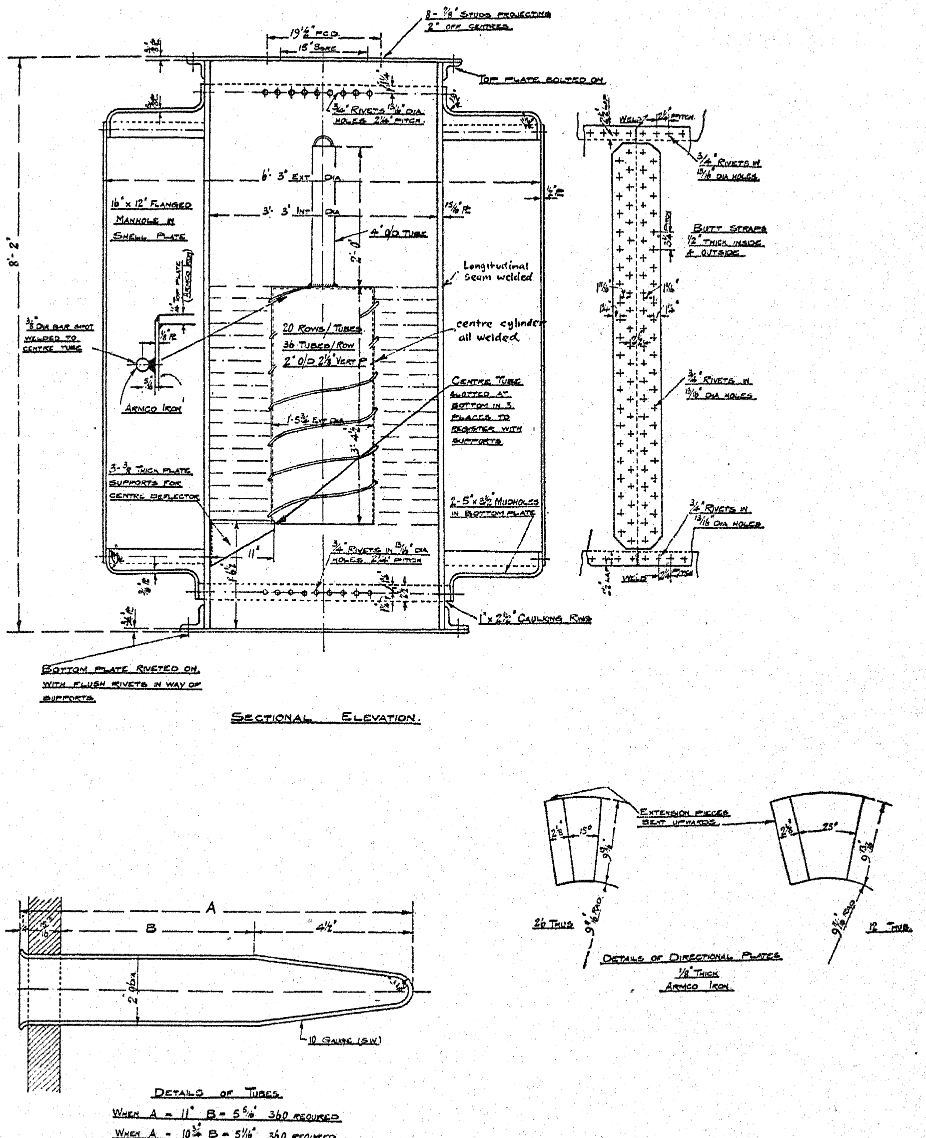


Fig. 3. Boiler installed for raising steam at working pressure of 120 lbs. per sq. in.
See also page 817a.

This has an important effect upon the cost of the units and suggests the advisability of consulting waste heat experts before finally determining the precise character of a waste heat installation. Full knowledge of insurance and statutory requirements is essential to securing the best commercial and technical layout.

Waste Heat Boilers for Large Diesel Engines.—For large diesel engines, it is usual to provide boilers with wide water spaces permitting of internal examination without raising the outer shell. Fig. 3 shows a boiler installed for raising steam at a working pressure of 120 lbs. per square inch from the exhaust gases from a Crossley Premier vis-a-vis engine of 1100 B.H.P. installed at the works of Messrs. Hoffman Manufacturing Company at Chelmsford, England.

The detailed drawing shows that the inner tube plate of the pressure shell has a longitudinal weld, as also the centre deflector. This boiler was built in 1937, and is fitted with stepped spiral divisional plates.

"Steddyflo" Boilers.—"Steddyflo" waste heat boilers were invented to provide commercially economic units for operation with low temperature gases, the name being derived from the fact that there is a "steady" flow of water from bottom to top inside each small watertube, and a continual state of "eddy" flow of the gases through the tube nest on the gas side. These boilers are especially helpful in dealing with low temperature gases from two-stroke engines.

For two stroke engines these boilers are little more than half the size and weight of waste heat boilers of other types, and very much more convenient in arrangement.

From Gibson's Tables it is noted that rates of heat transfer per square foot of heating surface vary considerably with speed of flow and size of watertube. The higher the speed of flow, or the smaller the size of the watertubes in the tube nest, the greater the value of the factor indicating the rate of heat transfer.

Fig. 4 shows alternative arrangements of the boilers, the fundamental features of which are:

(1) The use of a carefully planned nest of short, vertical watertubes of small diameter through which nest gas from the diesel engine discharge is forced in a direction at right angles to the axis of the boiler.

(2) The arrangement of this tube nest so that it can be blown through with a steam soot-blower, and also be opened up for inspection and occasional thorough cleaning by removing inspection doors around the periphery of the boiler.

(3) The constructional planning of the boiler to provide openings for the entry and exit of the gas from the tube nest and also openings for the inspection doors, while still leaving sufficient of the containing shell to sustain the whole of the longitudinal bursting load on the boiler without throwing stress on the tubes in the tube nest.

(4) The incorporation of the tube nest within the boundary of a pressure shell in such a manner as to leave free opportunity for access and for overhaul and tube replacement.

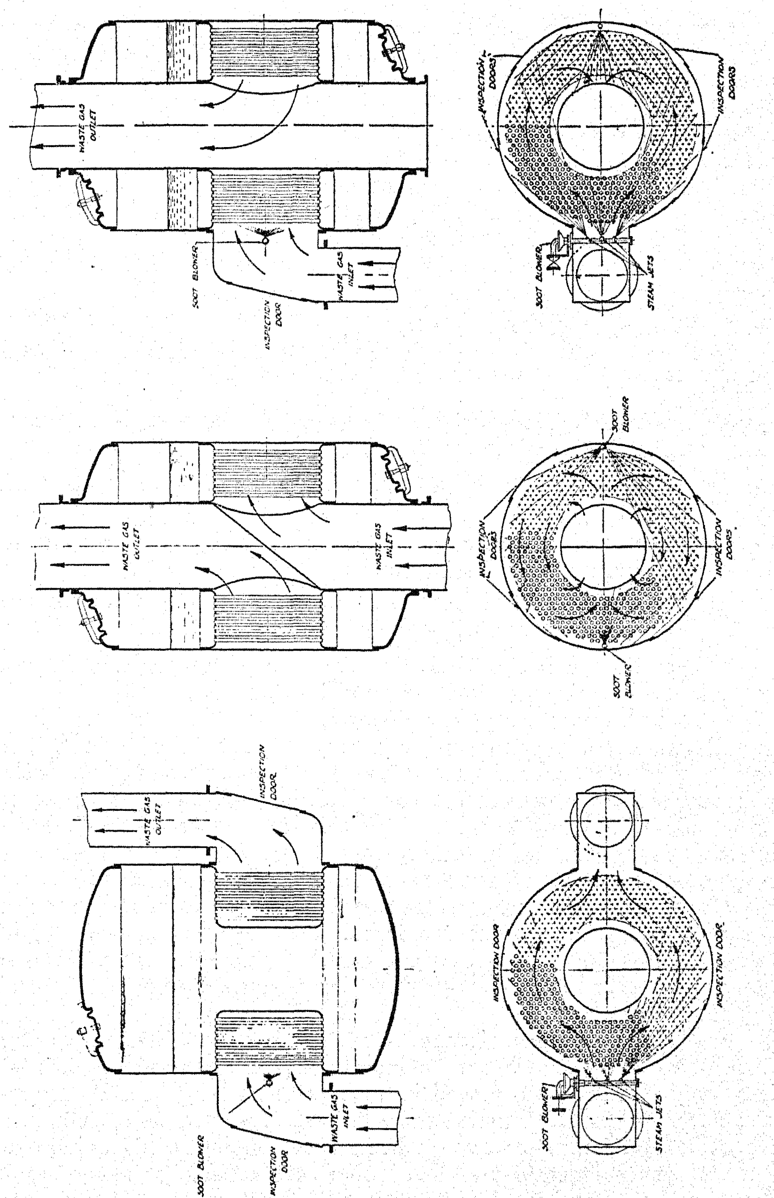


Fig. 4. Alternative arrangements of boilers.

Study of the designs will confirm that it is impossible to secure the full advantages sought for these boilers without the use of electric welding on the vertical cylindrical boundary shells and also on all pads, and gas connections.

One of these units was recently completed for a Norwegian oil tanker. Fig. 5 shows the manner in which this unit has been worked into the vessel. It will be observed that the boiler is linked up with the existing Scotch boilers in such a way that it required no special feed water arrangements or water gauges, the tube nest remaining "drowned" at all times owing to the manner in which it is arranged in the ship. This unit is designed to effect an economy in oil fuel consumption of approximately 1 ton per day at sea. The design and arrangement depends almost entirely for its commercial success on the use of welding. Apart altogether from the actual use of welding in the construction of the unit, fitting into the ship and connecting up to the existing gas, steam and water lines, could not possibly be carried out effectively and in a reasonable period of time, without the use of welding—a point of great commercial significance.

Direct-Fired Boilers and Water Heaters.—In their simplest economic form, vertical boilers and water heaters provide:

(a) A furnace space within which is released the heat contained in the fuel,

(b) Water-cooled surface around the furnace exposed to radiant heat from the burning fuel, and

(c) Some form of heating surface adapted to absorb heat from the hot products of combustion on their way to the flue.

In "Spiralflo" boilers and water heaters of welded design, these three requirements are provided in the most efficient manner possible.

In all such units a large clear firespace is provided surrounded by an annular waterspace, the internal boundary of which is formed of an electrically welded cylinder or cone of plating. At its upper edge this firebox plate is electrically welded to a tube plate into which are expanded the open ends of the thimble tubes. This thimble tube nest forms the most effective arrangement of heating surface so far invented for combing the heat from the gaseous products of combustion. By the use of this arrangement of thimble tube nest combined with the large area of radiant heated furnace plating forming the combustion chamber, it is possible to guarantee a higher output of steam per square foot of heating surface than can be guaranteed with any other type of vertical boiler of commercially competitive design.

It will be noted that electric welding is an essential feature of these designs, all of which are new to American practice, and most of which have only recently been placed into active service in Great Britain and Denmark. "Spiralflo" boilers can be designed for all types of fuel, being especially suitable for services requiring boilers giving relatively high outputs on small dimensions. These boilers are capable of being heavily forced without damage, provided care is taken to supply good feed water.

Composite Boilers.—As a preface to this section of the paper it should be explained that the demand for "composite" boilers, that is, boilers which can raise steam from waste gases and also from direct firing at one and the same time, arose originally in connection with marine work. A short survey will serve to establish the great importance of this

type of boiler, and to confirm that yet another branch of engineering owes a good deal to the introduction of electric welding.

When it was first demonstrated that sufficient steam could be raised from the waste gases from marine diesel engines to enable essential auxiliary machinery to be run at sea, the function of the direct-fired donkey boiler, otherwise necessary at sea, was reduced to that of meeting steam requirements in port. This at once suggested the possibility that the unit which raised steam from waste gases at sea might be utilized, alternatively, to raise steam from direct firing in port, thereby enabling the usual donkey boiler to be dispensed with.

Efficient "Spiralflo" boilers of "alternative purpose" type are in service at the present time, but there are disadvantages attached to the use of alternative purpose boilers notably:

(a) The boiler must be changed completely over to direct firing when the output from waste gas falls below a certain minimum requirement.
(b) It is not possible to boost an alternative purpose boiler by direct-firing to meet an emergency need at sea—say a fire, or a call for extra pumping services.
(c) The matter of changing over from waste gas to direct-firing involves the need for great care, especially if the main engines have to be kept running.

By the introduction of "composite" boilers these disadvantages have been entirely removed, and it is now possible to:

(a) Continue to recover heat from the waste gases no matter how slowly the main engines may be running
(b) Supplement the output from waste gas by lighting up the direct-fired section, and, therefore, to obtain the total of the combined outputs in special circumstances.
(c) Replace positive change over gas valves by simple directional valves arranged to divert the gas to the silencers instead of through the boiler tube nest, should it be desired to cut down the output of steam from waste gas in order to conserve feed water.

Further, in the case of composite boilers here discussed, it has been possible to secure these advantages while at the same time producing a boiler which is smaller in diameter, lighter in weight, and much more convenient in layout than alternative purpose boilers, even if these are of special design.

By taking advantage of composite boiler designs, it is possible to secure economical heat recovery from diesel engine exhaust whilst maintaining the convenience of having a direct-fired heat supply available when need arises—this with only one unit to instal and maintain. The initial cost of a composite unit of this type is generally appreciably less than the cost of two separate units.

It is in marine service, however, that the greatest call arises for composite boilers, and Fig. 6 shows photographs of these boilers in different stages of construction. The design owes its commercial practicability entirely to the use made of electric welding. The boilers combine two distinct and separate sections—one arranged to extract heat from the exhaust

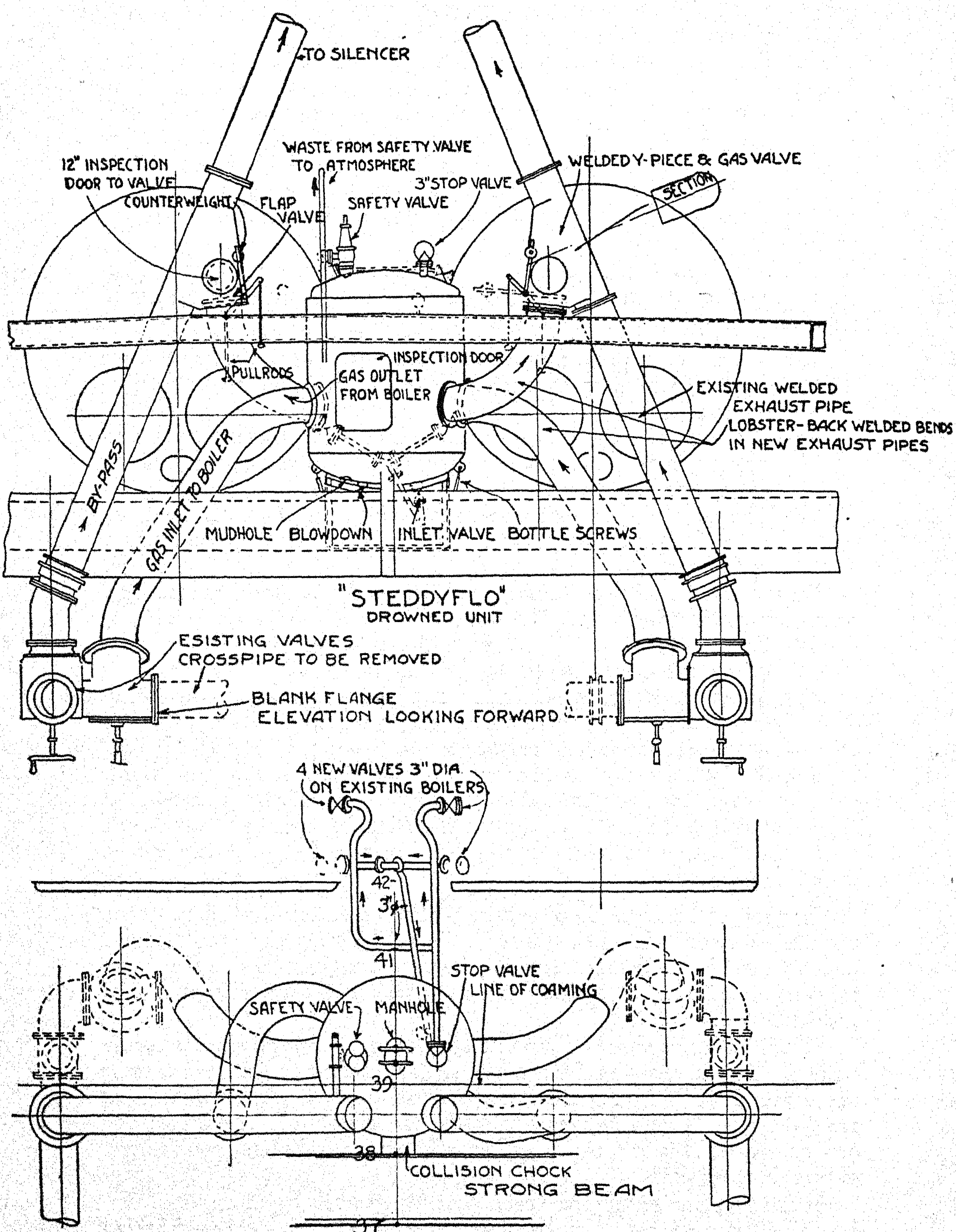
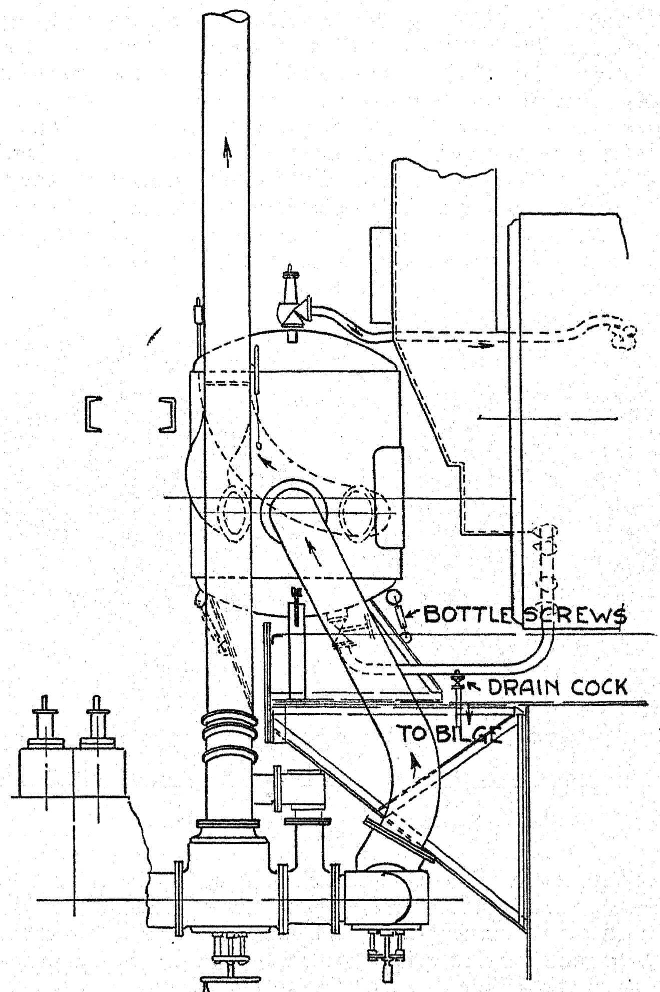


Fig. 5. Installation of unit in vessel. **See also page 821b.**



ELEVATION LOOKING TO PORT

THIS LAYOUT HAS BEEN PREPARED FROM PRINTS OF SHIP DRAWINGS, AND IS FOR GENERAL GUIDANCE ONLY.

WEIGHT OF "STEDDYFLO" WHEN EMPTY	4.45	TONS
WEIGHT OF WATER IN "STEDDYFLO UNIT	4.00	"
APPROX. TOTOL	8.45	"

MV "PRESIDENT HERRENSCHMIDT"

PROPOSED ARRANGEMENT OF "STEDDYFLO" UNIT

Fig. 5. Installation of unit in vessel. **See also page 821a.**

gases coming from diesel engines, the other section deriving its heat directly from fuel burnt in the furnace of an ordinary "Spiralflo" boiler.

It is of great technical concern that the design of such boilers should avoid all chance of unfair strain, or of distortion of the structure of the boiler due to temperature effects arising from the operation of one section of the heating surface without the other. In composite boilers there is no constructional link between the two sets of heating surface nor any chance of unbalanced stress causing objectionable distorting strains. The unit is of annular design, differences in temperature along the axial length of the boiler dispersing themselves easily in the main and detail structure of the boiler without giving rise to unfair strains.

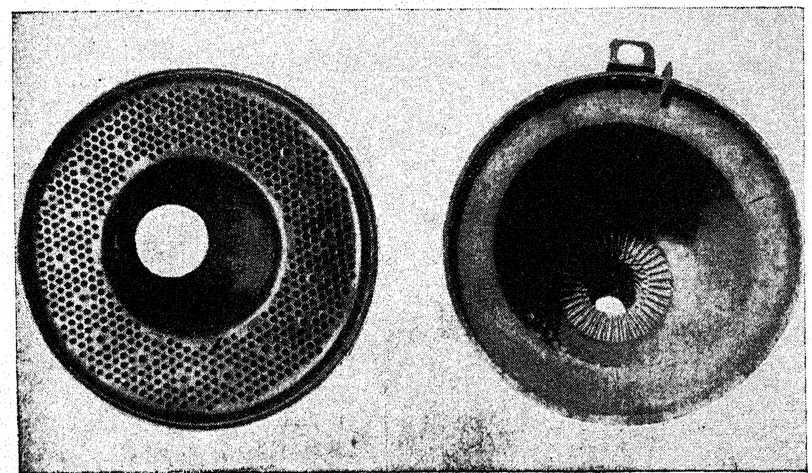


Fig. 6. Boiler in various stages of construction.

The arrangement of the structure of the boiler in way of the tube nest provides shell material adequate to prevent any longitudinal stresses from falling upon the watertubes due to the steam pressure within the boiler, while at the same time ensuring that the tube nest will sustain itself in position without straining its connection to the outer shell.

The design of the oil-fired section provides all the special features of a direct-fired boiler, notably the completely welded inner shell, furnace, tube nest and flue, all arranged so that there is ample freedom for the boiler to "breathe" and an absence of double thickness of plating likely to cause over-heating.

These boilers could not have been made a commercial proposition had it not been for the facilities afforded by electric welding.

Future Developments.—In the foregoing, attention has been directed only to waste heat recovery from diesel engine exhausts, and to the use of thimble tube nests surmounting direct-fired furnaces in vertical boilers. It is now proposed to indicate further directions in which great opportunity exists for the development of electrically welded designs of such units.

Induced Draught Layouts.—A waste heat unit used on the exhaust of a diesel engine performs a dual service—it recovers waste heat from the discharge, and also acts as a silencer. In designing such a waste heat unit, advantage is taken of the energy in the exhaust gas discharge to cause it to pass through the waste heat unit at a very high velocity, the transfer of heat from hot gas to water-filled tubes being greatly assisted by increasing the speed at which the gas passes through the tube nest.

Discharge from a multi-cylinder diesel engine takes place in a continuous series of impulses, one from each cylinder. The resistance presented by the waste heat unit is not greatly in excess of the back pressure due to the fitting of a silencer, and is often less than that arising from a silencer and a long length of exhaust pipe, owing to the cooling effect of the waste heat unit and the subsequent reduction in frictional loss after the gas has passed the waste heat unit.

The problem of recovering heat from supplies of waste gas coming from sources supplying gas at comparatively low temperature, and devoid of any initial energy of discharge such as exists in the case of an internal combustion engine, involves either the use of a very large amount of heating surface owing to the gas having to pass through the tube nest at a very low speed, or else the use of considerable fan power to speed up the rate of flow of the gas. Either solution is generally expensive and uneconomic.

There are many services, however, in which a "Spiralflo" waste heat unit can be used for recovery of heat from supplies of hot gas at very much higher temperatures than those associated with the discharges from internal combustion engines. As, for instance:

(a) Hot products of combustion from direct-fired furnaces in boilers of different types, and

(b) Waste gases from coking furnaces in gas making plants, re-heating, and similar furnaces in steel works, and other types of industrial furnaces.

The combination is believed to be new to industry, the basic idea being that of providing:

(1) Simple vessels of cylindrical design having furnaces within which heat is released from suitable fuel, this heat being transferred directly to water contained within the pressure shells by contact and direct radiation;

(2) Specially designed watertube nests through which the hot gaseous products of combustion are induced to flow, these watertube nests "combing" the maximum possible amount of heat from the products of combustion; and

(3) Such a subdivision of heating surface between the two units that water is discharged from the second unit to the first when it reaches steam temperature.

Apart from the pressure unit itself, use is made of electric welding for the construction of the flues, connections for the motor driven fan, spiral deflector and other auxiliary parts of the plant.

Welding Technique.—All "Spiralflo" and "Steddyflo" units are constructed to classification requirements according to the particular service for which they are required, or the wishes of clients.

Welded joints are used wherever this is possible, convenient for construction, and within the capacity of the firms building the units. In this connection, attention must be drawn to the fact that the requirements of insurance authorities are not uniform, some being prepared to place greater reliance upon welding than are others.

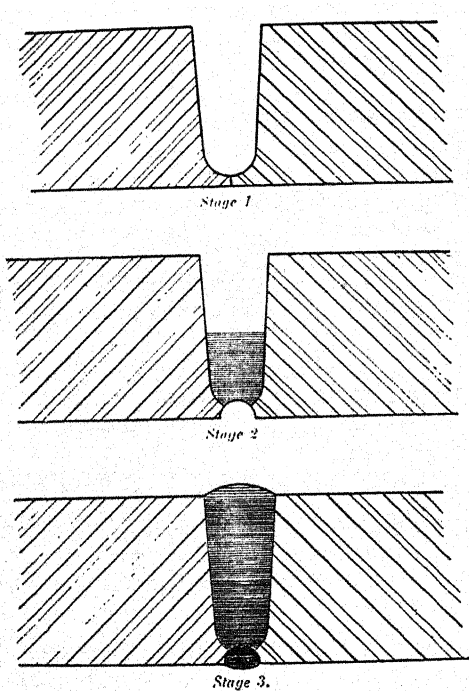


Fig. 7. Type of butt weld used in boiler construction.

From the outset the designers have concentrated on securing the utmost service from electric welding along consistent and progressive lines.

The requirements of Lloyd's "Register of Shipping" have been taken as the basis on which the designs of all large units have been calculated, structural details being chosen to suit the plant and methods of working of one of the leading boiler manufacturing firms in Great Britain—Messrs. John Thompson (Wolverhampton) Limited, to whom, as also to Lloyd's Register, the author would like to express thanks for much helpful criticism and advice.

Figs. 7 and 8 are taken with the author's permission from a paper read by Mr. J. H. N. Thompson before the Manchester & District Asso-

ciation of Gas Engineers, and give a good idea of the excellent work done by Messrs. John Thompson (Wolverhampton) Ltd.

All tensile, bending, impact and other tests have been carried out in Messrs. John Thompson's own laboratory, and also all macro and micro-structural investigations. All important welded pressure work has been properly heat treated in controlled furnaces, the completed boilers representing the highest grade of welded construction.

A large number of small, fully automatic, direct-fired steam raising boilers have been built to the requirements of British and Foreign Government Authorities by Messrs. Towler & Son, Ltd., of Stratford, London, England. These boilers have both inner and outer shells electrically welded, heat treatment being called for to meet specification requirements. In the construction of these boilers multiple runs of electrodes were used.

Fig. 8. Pneumatic chipping of groove from inside.

Details of the results of tests of all-weld-metal specimens and welded joints have not been included as these are usually well above specification requirements, a circumstance which is typical of electrical welding work carried out by competent workmen.

Conclusion.—In concluding, the author desires to state, definitely, that but for electric welding, practical development of many of his inventions would have been almost impossible. At every turn, problems arose which could only be solved in a commercially practicable manner by the use of electric welding.

In these circumstances it is extremely difficult to give chapter and verse as to:

1. Proportionate cost saving in percentage of the design described in the paper over previous design and previous method of construction.
2. The gross savings accruing to industry through the general adoption of the design described.
3. Increased service life, efficiency and general economy and social advantage provided to mankind by the design described.

However, in lieu of specific information in regard to the three points mentioned, it can be stated that, since the introduction of these designs, orders have been received for over 60 boilers, ranging from units suitable for quite small outputs, to boilers having outputs of over 10,000-lbs. of steam per hour. These orders have been secured in competition with boiler makers having their own plants, a fact which proves the economic virtue of the designs illustrated, since those responsible for marketing the boilers described in this paper have had to purchase the boilers from boiler-making firms and, therefore, pay the boilermakers profits as well as secure profits for themselves.

Apart from the fact that the boilers have been sold competitively, it must be recognized that the users have benefited directly from the fact that these boilers are lighter, smaller and more efficient than they could have been had attempts been made to construct them by riveting.

In an effort to refer directly to the three points mentioned above, the author would like to advance the following:

(1) That the results of the competitive entry of these boilers into the market for waste heat boilers indicates that the methods which have been adopted in their design and construction has resulted in a saving over other designs of from 10 to 15% in the cost of construction of boilers of equivalent output.

(2) That the gross savings to industry as a result of the introduction of these commercially economical waste heat boiler designs, especially for small engines, and large 2-stroke engines, amount to very large figures. It is now generally possible to save the cost of the waste heat unit in the first 2 or 3 years of operation owing to the overall efficiency being increased from 10 to 20%. This means that users of these new designs of waste heat boilers will save from 10 to 20% of their fuel cost after the lapse of from two to three years required to cover the capital cost of the waste heat installation.

Until these economical waste heat units had been produced in accordance with the designs described in this paper, relatively few users of diesel engine plants in particular had taken advantage of waste heat recovery. In marine service the introduction of 2-stroke engines, delivering large volumes of low temperature exhaust gas, in place of 4-stroke engines delivering much smaller quantities of exhaust gas at a much higher temperature, caused many owners to give up all thought of securing heat recovery

by reason of the tremendous size of the waste heat boilers necessary. This state of affairs has been entirely altered by the introduction of "Steddyflo" boilers, designs of which necessarily involve the use of electric welding.

(3) The advantage of welding in eliminating the risk of leaking joints, in "un-get-at-able" positions in boilers subjected to severe service, is bound to give increased service life, while the elimination of space occupied by riveted joints, and needed to obtain access to riveted joints, results in securing improved efficiency in the designing of the gas passages in the boiler, and also in providing the necessary heating surface.

These points can be followed individually in the different designs, and it would not appear necessary that they should be set out in lengthy detail.

Finally, in reference to this particular paper, the author would like to remark briefly that but for the major technical and commercial successes which have followed the construction of large boilers at the Works of Messrs. John Thompson (Wolverhampton) Ltd. this paper would not have been written.

Chapter III—All-Welded Economic Type of Boiler

By HUGH B. FERGUSON and EDWARD F. BURFORD,
Director and chief draftsman, respectively, G. A. Harvery and Co., London, England.

Only those who are familiar with the difficulties encountered in the past with the authorities and insurance companies in the United States and Great Britain, in obtaining authorization and acceptance of welded boiler drums, can appreciate the difficulties that had to be overcome to obtain an insurance company's agreement to the first all-welded boiler of any size to be manufactured in England. The major new insurance risks requiring consideration were the larger diameter of shell and flat ends, compared with a boiler drum, and the breathing of the ends due to expansion and contraction of the welded flues necessitating weld metal capable of sustaining fatigue stresses.

As far as alteration in design of a riveted boiler to a welded one is concerned, this presented no difficulty, especially as it was felt that departure from standard practice from the orthodox dimensions of a similar type of riveted boiler was not advisable or necessary in this first effort to obtain an insurance company's permission to make an all-welded boiler.

It so happens that the firm by whom the authors of this paper are employed has installed two riveted boilers of about eleven million B.T.U's capacity, working under a steam pressure of 180 lb. per sq. in. for high pressure water heating of the factory. The last of these two riveted boilers was manufactured some two years ago, and therefore, the cost of the riveted boilers originally made is comparable with the present welded boiler recently manufactured.

Preparatory Work.—About a year ago, our firm manufactured four very large welded evaporators, which are now in successful operation, and it was to no small extent the background of the welding data for these high pressure evaporators that encouraged our firm, and gave confidence to the insurance company, to consider an all-welded boiler. A short description of one of these evaporators by the Authors follows and forms, for the reasons given above, an important part of this paper.

Welded Evaporators.—The four evaporators here described are claimed to be the largest welded pressure vessels so far made to Lloyd's Class 1. Code. Designed for a pressure of 250 lb. per square inch on 11-ft. diameter, all four evaporators are very similar, and it will suffice to describe No. 1, which has an internal diameter of 11-ft. and a total height of 26-ft. 9 in. It is composed of two shells, each 10-ft. 4 in. high, a domed bottom just over 3-ft. deep, and a domed cover of the same depth. The bottom shell is known as the Calandria section, and has two tube plates, each in one piece and each 1 in. thick, welded with fillet welds inside and out to the shell at about 7 in. from each end. There are 1,792 tubes of 1½ in. bore, No. 8 gauge, and 9-ft. 0½ in. long, connect-

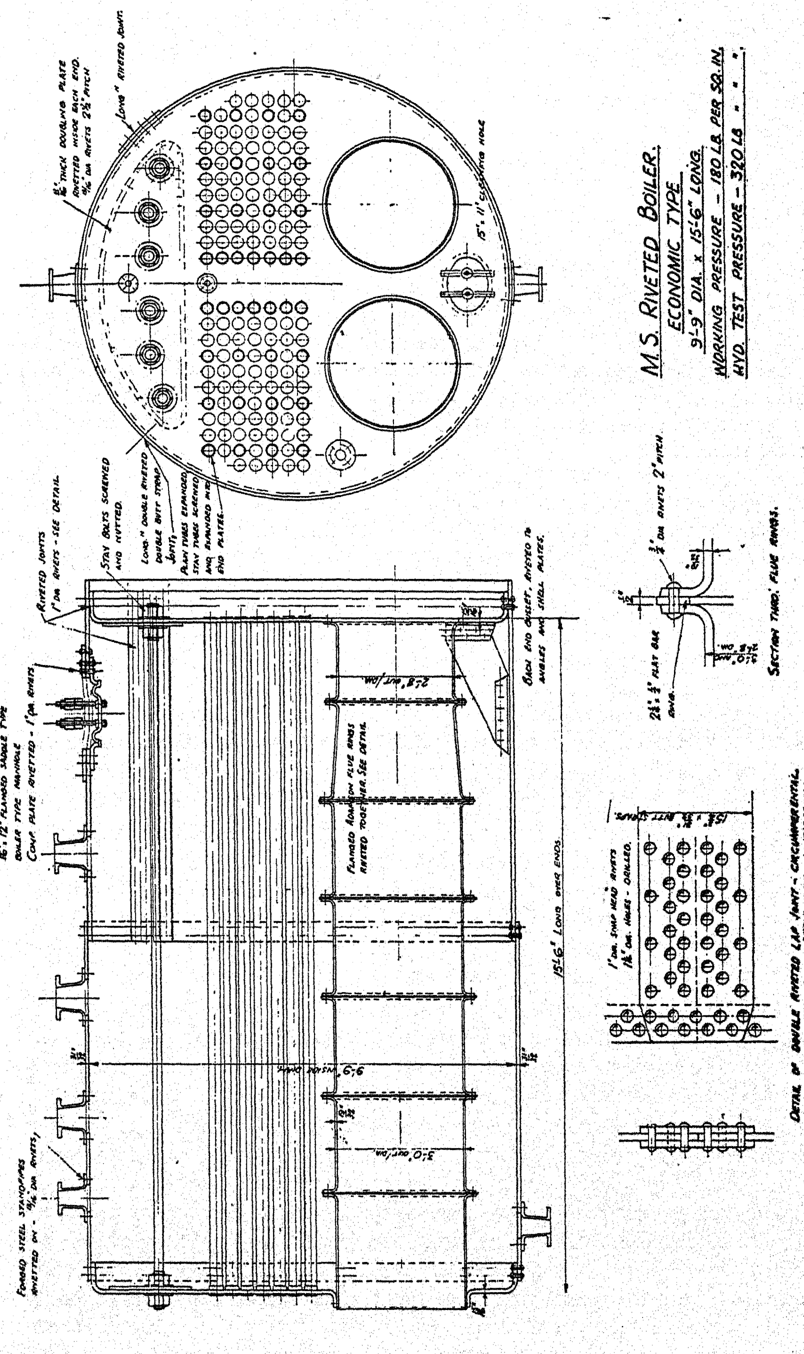


Fig. 1. Boiler design for riveting.

ing the two tube plates. The tubes protrude $\frac{1}{4}$ in. above the plates and each is welded round. A central 2-ft. 6 in. diameter tube between the plates is $\frac{7}{8}$ in. thick. The thickness of the calandria shell is $1\frac{15}{32}$ in., and that of the top shell—$1\frac{1}{8}$ in. The bottom and top dished and flanged ends are $1\frac{3}{8}$ in. thick, have an 8-ft. radius of dish and a 12 in. corner radius. Both shell plates are in one piece, with one longitudinal seam, the ends also being made from one plate. Before dishing and flanging the plates for these ends had a diameter of 13-ft. $5\frac{1}{2}$ in. They were of the maximum width that can be rolled in England.

There are five main welds on each vessel—the two vertical welds of the bottom and upper shells, and three horizontal circular welds, one connecting the two shells and the other two joining the top and bottom ends of the shell. The working pressure of the calandria section of the vessel is 250 lb. per square inch, and the test pressure was 375 lb. per square inch. The upper shell and the two ends are subjected to 190 lb. per square inch, and were tested to 285 lb. The weight of the completed vessel is 48 tons.

All four vessels were completely fabricated in our shops and lifted 160-ft. from the ground to the fourth story of a new works. They were not only built to conform with Lloyd's Class 1. Code for welded pressure vessels but were also independently surveyed by another leading Insurance Company to the A.S.M.E. Code.

A photograph of one of the evaporators is shown in Fig. 2.

Advantages of a Welded Over a Riveted Boiler.—1. The piercing of the shell is confined to the tube holes for the end plates and the fittings, which reduces to a minimum the possibility of leakage and trouble with rivets, particularly when boilers are started up continually from the cold.

2. Trouble with embrittlement of the plates around, and adjacent to rivet holes where the plate has been work hardened is done away with.

3. As the whole of the shell and flues for the welded boiler have been heat treated separately in a large furnace at 650°C. before the boiler is installed, most of the locked-up manufacturing stresses are eliminated, whereas with a riveted boiler there are severe local stresses, and it is well known that the corrosion of steel is much more severe in the neighbourhood of very high locked-up stresses.

4. It was estimated that a considerable saving in cost of a welded over a riveted boiler could be anticipated, and this has proved the case. This is shown by the comparison of cost, at the end of this paper, between a riveted and a welded boiler, each of exactly the same size and output.

5. The most important incentive for pushing welded construction was that we realized there is a large market for Economic and Lancaster Types of Boilers, with resulting keen competition in price. Once the welded type of boiler is established with the insurance companies we foresee a large new field for welded work, as our firm is more competitive in welded work to class 1 requirements, with our testing laboratory, X-ray apparatus, heat treatment furnaces, and trained welding personnel, well established. It was to produce this new field for welded work that we took so much pains with the preparatory work for this job.

General Design of a Welded Boiler.—Fig. 1 shows the economic dryback boiler 9′9″ diameter for 180 lb. steam working pressure and 9,600 lb. per hour evaporation, of riveted construction.

Fig. 3 shows the design of the fusion welded boiler now under dis-

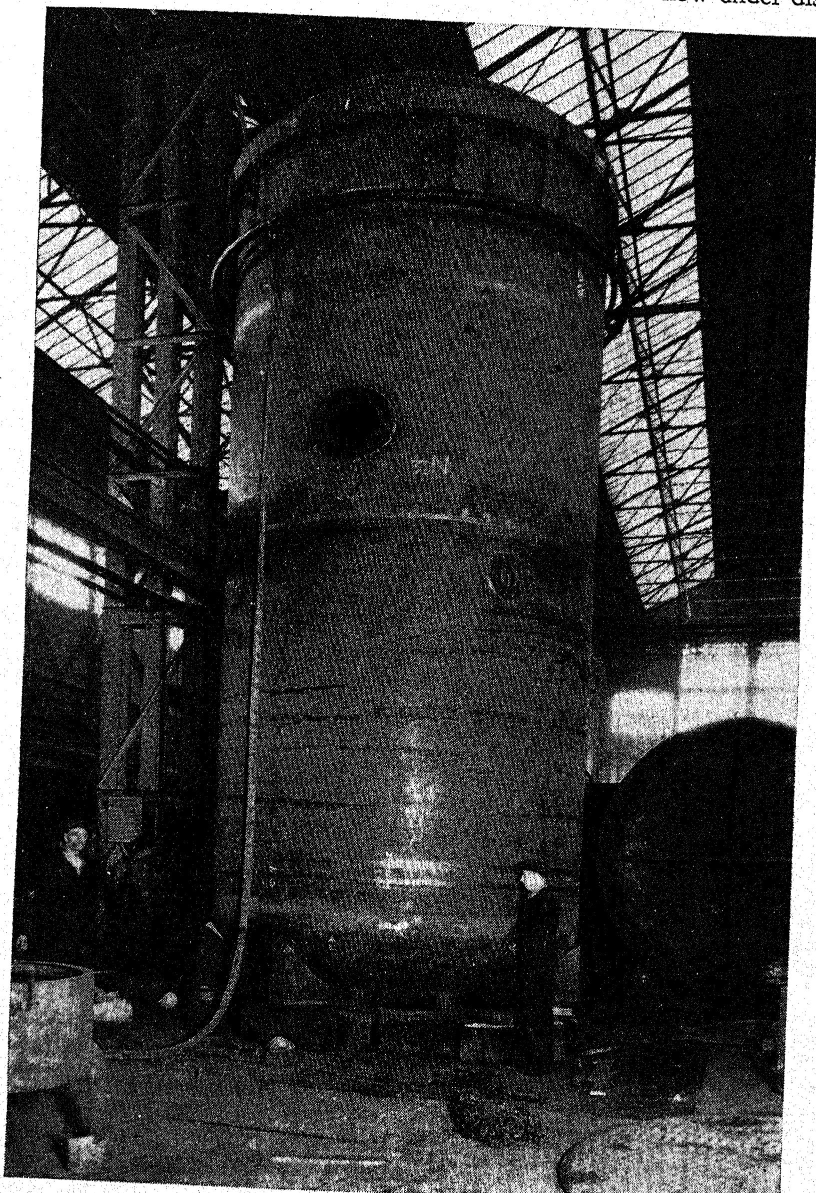


Fig. 2. Largest welded pressure vessel ever built to Lloyd's Class I requirements. Welding data on this evaporator encouraged development of all-welded boiler.

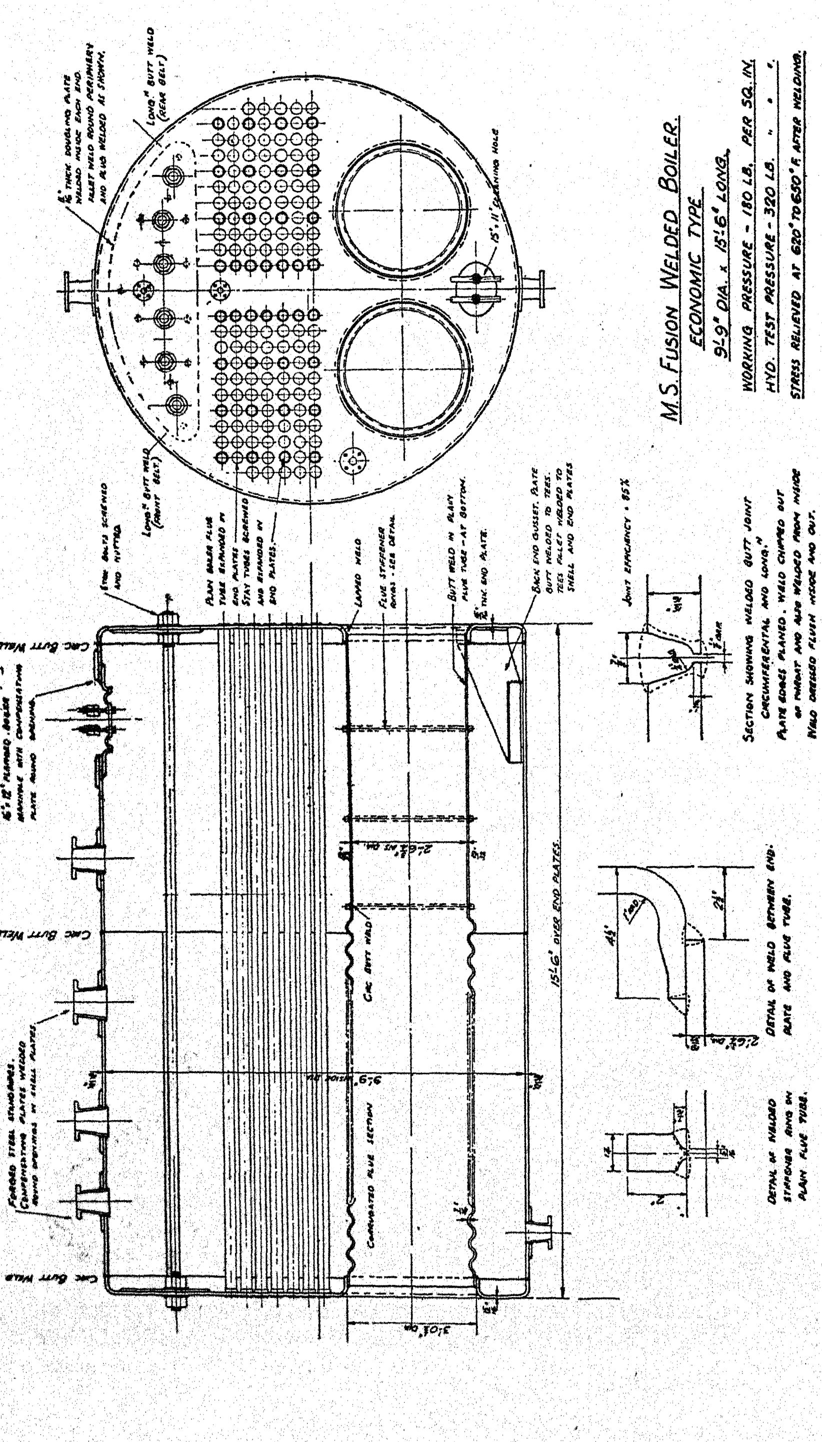


Fig. 3. Design of arc welded boiler.

cussion—9′9″ diameter for 180 lb. steam working pressure and 9,600 lb. per hour evaporation.

The welded joint efficiency allowed by Messrs. Lloyds "Register of Shipping" on a welded boiler is 85% and this is quite as high as that of a treble-riveted butt joint. It was therefore decided to conform with Lloyd's Class 1 requirements for fusion welded vessels intended for land purposes, which are very similar to the A.S.M.E. code.

The boiler also had to match up with the existing riveted boilers so that in some respects we were restricted in design.

Constructional Details.—

Shell plates are $^{15}/_{16}''$ thick. All joints butt welded using a single U type joint.

End plates and flat and flanged round the edge and for the furnace tubes, thickness of plate $^{15}/_{16}''$.

Furnace tubes are made, 50% in length as a corrugated flue to take up the expansion. The remainder is of electrically welded tube, thus eliminating the many circumferential riveted joints which would occur in the flanged flue rings as used in riveted Boiler. The compensation for the plain flue tube is provided by rings of flat bar section welded round the outside of the tubes in the water space, the diameter of these rings permitting the flue to be withdrawn through the front flue hole, for subsequent replacement.

Standpipes are of forged steel without base flange but compensated round the openings cut in the shell plates by means of external compensating plates welded on.

Smoke tubes and stay bolts. It was decided to adhere to the practice of expanding in the plain tubes, screwing in and expanding the stay tubes, screwing and nutting the stay bolts, although the welding in of all these items could be effectively carried out.

Fabrication.—All plate edges were planed for welding, using throughout a single U type butt weld.

All seams, both longitudinal and circumferential, were examined by X-ray. The total footage of seam thus examined was 111 lineal feet. A penetrameter 0.01 inch thick attached to the shell showed clearly on each exograph.

The welders employed have had three years' continual practice at Class 1 X-rayed welding and except for two small inclusions of slag no cutting out of the welding for defects was necessary. In no place did any of the exographs show lack of penetration or porosity.

Mechanical Tests, Chemical Analysis and Micro Examinations.— Two coupon plates were welded simultaneously with the longitudinal welds of the boiler shell seams, one at the end of each longitudinal seam (the boiler being in two belts). These coupon plates were heat treated with the boiler at 650°C. and the plates were machined, very similar to the A.S.M.E. Code requirements, and the following tests were made at our company's works. The tensile machine used is a very accurate instrument, calibrated by Messrs. Lloyd's and guaranteed to one-tenth of one percent of accuracy. The following table gives results.

1. TWO TENSILE TESTS FOR JOINT SPECIMENS

Specimen No. 1

Area across the weld	0.7785 sq. in.
Ultimate strength per sq. in. of original area	30.7 tons

Broke in Weld—Fracture Silky.

Specimen No. 2

Area across the weld	0.7000 sq. in.
Ultimate strength per sq. in. of original area	30.2 tons

Broke in weld—Fracture Silky.

2. TWO ALL WELD METAL SPECIMENS

Specimen No. 1

Diameter	.437 inch.
Withstood max. stress of	30 tons per sq. in.
Yield	18.9 tons per sq. in.
Elongation in 2"	25%
Reduction in area	54.7%
Fracture	Silky

Specimen No. 2

Diameter	.451 inch.
Withstood max. stress of	29.8 tons per sq. in.
Yield	19.1 tons per sq. in.
Elongation in 2"	28%
Reduction in area	56.2%
Fracture	Silky

3. **FOUR IZOD IMPACT TESTS.** Usual 10 mm square specimens, 75 mm long, were made up and notched, the notch being 2 mm deep x 1/4 mm bottom radius. Sides of the notch at 45° angle from one another, the hammer striking 22 mm from the notch.

Specimen No. 1
Notched at junction of weld and plate.
Energy absorbed 74 ft.-lb.

Specimen No. 2
Notched at junction of weld and plate.
Energy absorbed 54 ft.-lb.

Specimen No. 3
Notch at middle of weld.
Energy absorbed 62 ft.-lb.

Specimen No. 4
Notch at middle of weld.
Energy absorbed 59 ft.-lb.

4. **TWO BEND SPECIMENS** 7/8" thick, 1 7/8" wide after polishing, were made up the full thickness of the plate and bent round a former of a radius one and a half times the thickness of the plate until the limbs were parallel.

Both these bends, one inside and the other outside, showed no signs of fracture after bending.

One Bend Specimen to Lloyd's Register of Shipping requirements. Dimensions—3/4" wide x 3/8" thick. Cut flush with the upper surface of plate and bent cold through an angle of 180° until distance between the inside of parallel sides was 3/8".

No cracks appeared.

5. **TWO FATIGUE TESTS** were made on the weld metal, using a "Haigh" push-pull type of machine.

Specimen No. 1

Diameter	0.495 in.
Applied stress	± 10 ton/inch^2
Endurance	0.616 million stress cycles

Fracture originated at a very small gas hole close to the surface.

Specimen No. 2

Diameter .... 0.500 in.
Applied stress ....± 8 ton/inch^2
Unbroken after 56.794 million stress cycles.

Note.—These tests indicate that the weld metal will stand a fatigue range of ± 8 ton/inch^2, i. e.—16 ton/inch^2.

Materials.—The boiler plate was mild steel of 26/30 tons tensile per square inch, showing 23% in 8″ elongation, annealed at the mills.

6. CHEMICAL ANALYSIS OF PLATES.

C.	.21%
P.	.044%
S.	.036%
Si.	.06%
Mn.	.38%

7. CHEMICAL ANALYSIS OF WELD METAL, was also made in our laboratory and gave the following results:

C.	.14%
P.	.037%
S.	.031%
Si.	.08%
Mn.	.38%
Nitrogen	.014%

8. MICRO AND MACRO PHOTOGRAPHS were taken of the welded joint.

After tubing, the boiler was subjected to a hydraulic test of one and a half times the working pressure, which is equivalent to 320 lb. per sq. in.

The construction was supervised throughout by a responsible boiler insurance company and the boiler passed for service.

ACTUAL COST OF RIVETED BOILER

Materials	Weight in Lb.	Cost		
Plates	30,700	£ 206.	3.	6.
Rivets	1,900	17.	0.	0.
Flanged Adamson Rings for Flues	9,520	190.	0.	0.
Flat and Angle	580	4.	2.	0.
6 Standpipes	224	20.	15.	0.
6 Solid Steel Stays	1,680	34.	2.	0.
38 Screwed Stay Tubes	5,760	82.	19.	0.
114 Plain Tubes	8,400	104.	6.	3.
1—16″ x 12″ Saddle Manhole	340	13.	10.	0.
1—15″ x 11″ Manhole	224	5.	10.	0.
Sundries	140	3.	8.	9.
Total for Materials	59,468	£ 681.	16.	6.
Labour		235.	0.	0.
200% Overheads		470.	0.	0.
TOTAL ACTUAL COST WITHOUT PROFIT		£1386.	16.	6.
		$6739.40		

ACTUAL COST OF A WELDED BOILER

Materials	Weight in Lb.	Cost		
Plates	31,160	£ 211.	5.	11.
2 Fox's type Corrugated Flues	2,020	70.	0.	0.
6 Weldless Standpipes	168	14.	10.	0.
6 Solid Steel Stays	1,680	34.	2.	0.
38 Stay Tubes 3¼″ o. d. x 5/16″	5,760	82.	19.	0.
114 Ordinary Tubes	8,400	104.	6.	3.
1—16″ x 12″ Saddle Manhole	340	13.	10.	0.
1—15″ x 11″ Manhole	224	5.	10.	0.
10 Rings	780	7.	0.	0.
Tee Bar	35		6.	3.
Sundries	140	3.	8.	9.
Total for Materials	50,707	£ 546.	18.	2.
Electrodes		48.	0.	0.
		£ 594.	18.	2.
Labour		£ 170.	0.	0.
200% Overheads		£ 340.	0.	0.
		£1104.	18.	2.
X-raying, Mechanical Tests and Heat Treatment		84.	0.	0.
TOTAL ACTUAL COST WITHOUT PROFIT		£1188.	18.	2.
		$5778.45		

This shows that while only 10% profit on the cost can be obtained selling a riveted boiler at £1525. 0. 0. ($7401.50); 20% profit on the estimated cost could be looked for if the welded type was sold for only £1434. 0. 0., ($6969.24).

Chapter IV—Design and Construction of an 800,000-Gallon Welded Storage Tank

By Odd Jacobsen,
Naval architect, chief welding engineer and part owner,
Trosvik Verksted, A/S, Brevik, Norway.

About 20 years ago this shipyard decided to take up electric welding and now nearly everything produced is 100 per cent welded. Besides smaller ships and barges, the yard now builds steel structures, conveying machinery, mining outfits, apparatus and containers for the chemical industry, and is at present one of the largest producers of oil storage tanks in Norway.

These tanks are partly made in serial production and all sizes up to 10,000,000 litres (2½ million gallons), and may be divided in the following 3 groups:

Small tanks (up to 50,000 litres or 12,500 gallons). These are mostly finished in the shop and transported by ship or railway.

Average sized tanks (50,000 to 500,000 litres). Some of these are finished in the shop and some built on the site, depending on the location of the tank.

Big tanks—above 500,000 litres. Generally it is found most economical to erect these sizes on the site.

It is our method of building a tank of 800,000-gallon capacity which I am going to deal with in this paper.

Of the principal rules for all of our welded constructions may be mentioned:

(1) Use as few welded seams as possible, and spread the seams apart as far as practicable.
(2) Use buttwelding as much as possible; butt welds are preferred to fillet welds whenever there is a choice between these.
(3) Use a minimum of overlapping of plates and faying flanges of profiles against plates.

Only when passing from a thick to a considerably thinner plate is overlapping used—in the same manner as for the joining of flanges for pipes, shown in Fig. 1, and for the fastening of roof plates to top angle ring or plate, shown in Figs. 3 and 5.

You will also note that the shell plates are welded directly to the bottom plates without any circumferential angle, Fig. 2a. If a customer demands an additional stiffening, which I consider unnecessary, I will recommend a design as shown in Fig. 2b. This has also the advantage that the bottom is more easily tested.

The joining of the shell to the roof is shown in Fig. 3. As the roof plating of this tank is going to rest loose on the supporting profiles, and on account of the danger of explosions, have only a weak connection to the shell, this design was chosen. Of course an angle-bar

or T-bar as shown in Fig. 5 could be used, thereby obviating the overhead welding which the plate ring of Fig. 3 necessitates, but the latter is easy to bend and gives a simple connection of trusses and diagonals of the dome.

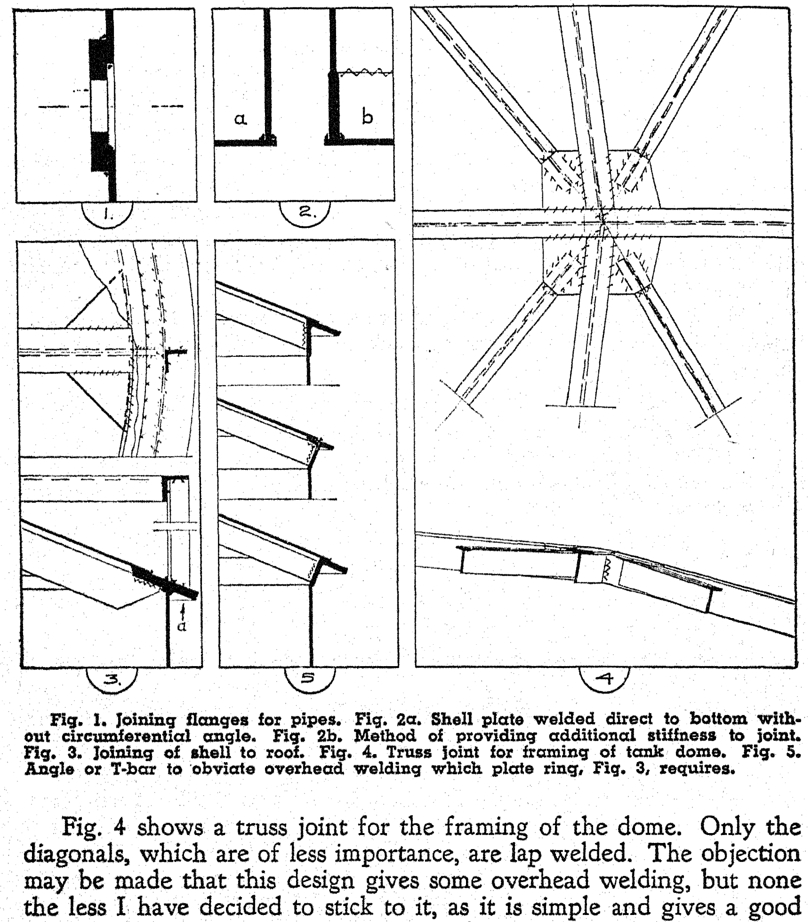


Fig. 1. Joining flanges for pipes. Fig. 2a. Shell plate welded direct to bottom without circumferential angle. Fig. 2b. Method of providing additional stiffness to joint. Fig. 3. Joining of shell to roof. Fig. 4. Truss joint for framing of tank dome. Fig. 5. Angle or T-bar to obviate overhead welding which plate ring, Fig. 3, requires.

Fig. 4 shows a truss joint for the framing of the dome. Only the diagonals, which are of less importance, are lap welded. The objection may be made that this design gives some overhead welding, but none the less I have decided to stick to it, as it is simple and gives a good transfer of forces in question. It has to be considered that the 4 plates are placed in different planes. Besides, the diagonals are welded to their bracket plates in the shop using jigs for positioning, and the roof structure is welded on the ground as later explained. Some overhead welding may therefore be tolerated.

On all tanks up to 600,000 litres, on which loose roof plates are not called for, we use to make the roof plates a little thicker and to make the trusses of flatbars on edge, as shown in Figs. 6 and 19. The rings and diagonals are then substituted by the plates.

When marking each plate, it is to be stamped as shown in Fig. 7. The position of the butt welds of adjoining strakes is marked with the numbers of the plates. Such marking makes the erection of the plates

for welding much easier. Both when laying off and when cutting the plates, great care must be taken that the measures are correct and the plates exactly square.

This applies in particular to the shell plates, as a single plate, seemingly only a trifle oblique, may cause a deformation of the whole shell.

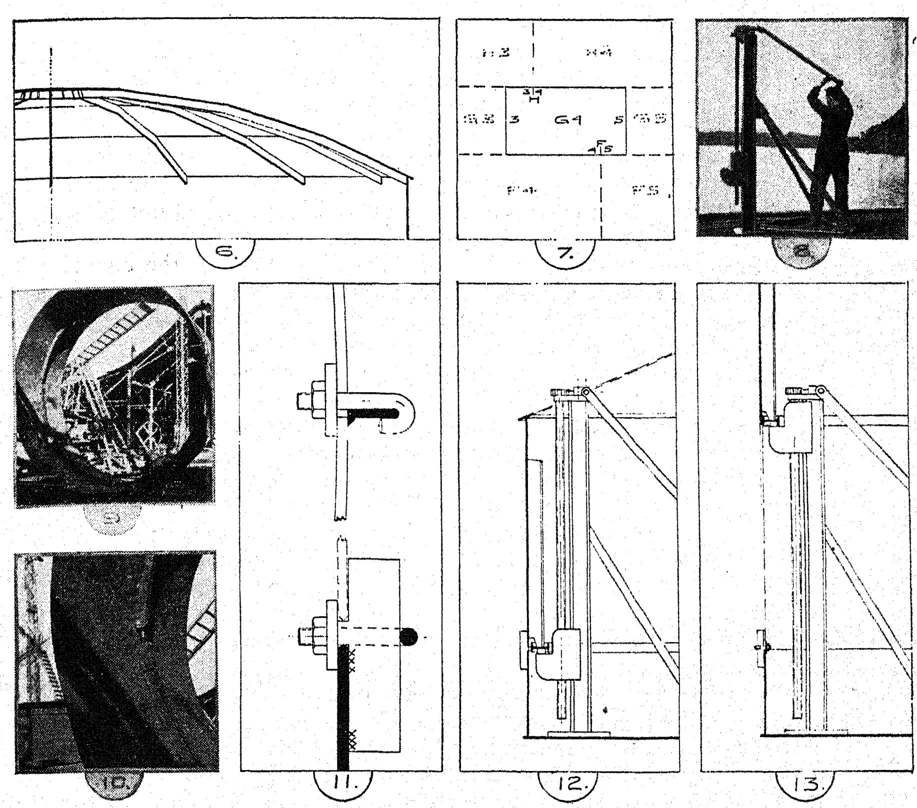


Fig. 6. Trusses for tank roof plates made of flat bars on edge. **Fig. 7.** Method of stamping plates. **Fig. 8.** Screw-jack. **Fig. 9.** Expansion ring in place. **Fig. 10.** Close-up of expansion ring. **Fig. 11.** Method of fastening flatbars around bottom strake. **Fig. 12.** Expansion ring placed on lifting console of screw-jack. **Fig. 13.** Expansion ring lifted.

As the principle of our method for erection and welding is based on a device which I may call an "expansion-ring", I must now speak a little further on this appliance.

The problem when welding big objects is always: How may the different parts be brought into exact position before tacking and welding? If no obvious solution appears, many designers only too often make use of overlap welding where considerations of design or esthetic reasons call for buttwelding. For many years, we have used small expansion-rings, as shown in Fig. 9, 10 and 19, for the adjusting of the shells for tanks and pipes, and the like is, I believe, in use at several shops.

An expansion-ring is screwed together and placed in the midst of the circumferential seam to be welded. Upon being screwed out, the expansion-ring evens out the two shells in relation to each other. Even if there should be a small difference in the circumference of the two shells, these will adjust themselves very well.

When welding with bare electrodes a copper strip is fastened on the expansion-ring. On welding against this strip, a smooth weld on the root side with 100% penetration is obtained. However, for still better quality, we now use shielded arc electrodes. We then use a more narrow gap between the plates and always weld a backing head on the reverse side of the seam.

The bigger the shell strakes are, the greater are also the difficulties of adjusting in any other way. If two strakes are placed together without staying off, and tacking is started from the marked out spots, some difficulties will often arise at the last tacking spots.

I, therefore, decided to use an expansion-ring even for the biggest tanks. The problem was to find a solution giving a ring which was stiff enough, easy to handle and not hampering the work in any way. It was, however, only after deciding to build the tanks "from the top down" that a good solution was found. This also provided a lot of other advantages.

The principle of building the roof and the upper shell strake first, lifting this dome up the width of one strake with jack-screws, building the next shell strake beneath, lifting again, etc., is old and has been used for the riveting of tanks. In this country it has been abandoned.

The use of this method for the welding of tanks, however, I have never seen mentioned in periodicals or other literature, and yet, in my opinion, it is particularly suited for this method of construction.

Method of Construction.—The tank will therefore be built in the following manner:

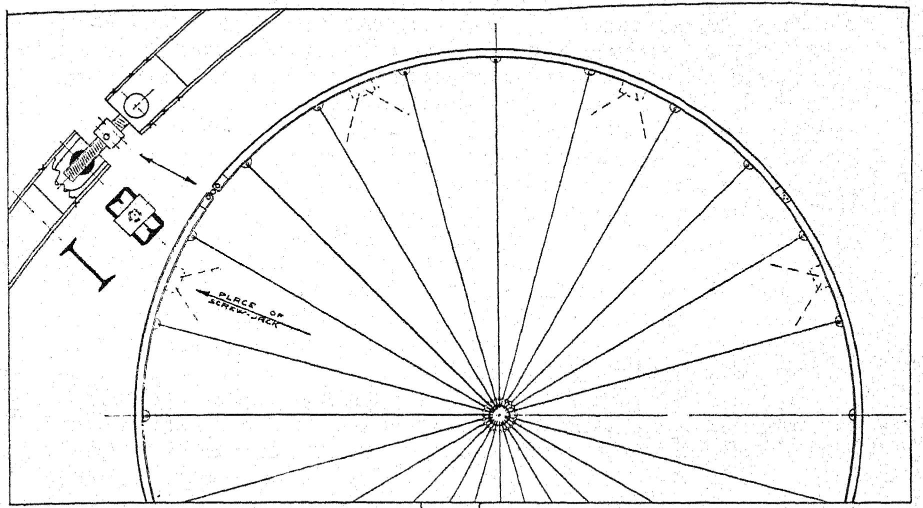
At first the bottom welds are welded on one side; the strakes are turned and welded on the reverse side.

On a low foundation of square logs the above mentioned strakes are placed in correct position to each other, tacked and V-welded. Where it may be necessary, the seams are chipped clean and welded on the reverse side from below.

The bottom is cut to its circular shape after welding is finished, preferably using a cutting machine. This cutting prevents some of the stresses at the ends of the seams and promotes a more even surface of the bottom.

Now the bottom shell strake is welded to the bottom. The single plates are first placed in position, the vertical butts welded from both sides, and then the strake is at first tacked and then welded to the bottom. This causes no difficulties, as the bottom is marked off to show the location of the shell.

The bottom shell strake is made as narrow as possible, with barely width enough so that the manholes may be located. Preferably, this strake should not have been welded on until at last, and then could have had the same width as the other shell strakes. The tank, however, is to be placed on a sand bed, and as the customer will possibly demand that



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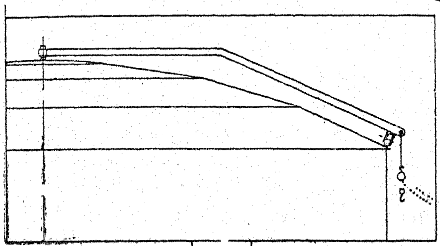

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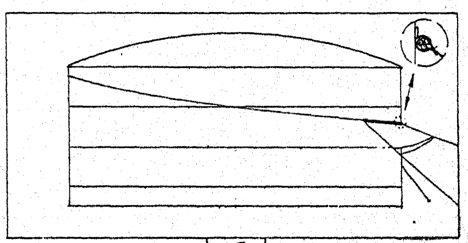

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Fig. 14. Details of expansion ring. Fig. 15. Swinging arm affixed to top of tank before it is lifted. Fig. 16. Use of partial tarpaulins to protect outside welding.

the bottom be tested with one foot of water before lowering, this first shell strake is made as narrow as possible. If the customer would be satisfied with a depth of water above bottom corresponding to a strake as shown in Fig. 2b., this design would have been at least as good.

The testing of the bottom finished, the logs are taken away and the bottom lowered onto the foundation. Now 8 screw-jacks of the type as shown in Fig. 8 are placed on the bottom in location and the back-stays of the screw-jacks tack-welded to the bottom. On the lifting consoles of the screw-jacks is then placed an expansion-ring, Fig. 12, of design as shown in Fig. 14.

To keep the expansion-ring as circular as possible, slender wire-stays are used, so that the ring resembles a bicycle wheel. All around the bottom shell strake are now fastened small flatbars in a manner as shown in Fig. 11. In these the plates of the top strake of the shell are now placed, and the vertical butts welded from both sides. The expansion-ring is now screwed out close to the top of the strake so that this strake assumes an exactly circular shape, and the "top ring" ("a" Fig. 3) put in place and tacked. Now the trusses and the centreplate are placed in position, being supported by a layer of square logs in the

middle. Both the upper shell strake and the trusses are now welded to the "top ring", the remaining skeleton of the dome is put in place, tacked and welded. At last the roof plates are placed in position and welded. This is done from the centre, welding first the plates in the inner ring together, then tacking the plates of the next ring together and to the first ring, and welding first the plates of the second ring together and then the seam between the first and second ring, etc. The last weld of the roof plates in this way will be their fastening to the "top ring". If the top strake of the shell is so narrow that the screw-jacks should prove to be the higher, the welding of the last plates of the roof must of course be postponed until the dome has been lifted somewhat. As the maximum height beneath the dome is not more than 4 metres, all places are easy to reach and only some small frames, which are easy to move, are needed to readily do the work.

Now, with the top of the tank just about finished, the expansion-ring is loosened and lowered to a position as shown in Fig. 12. Over each of the lifting consoles of the screw-jacks a piece of structural shape, as shown, is tack-welded to the shell to transfer the weight of the dome in a safe manner to the screw-jacks. The whole dome is now lifted a distance which allows the next shell strake to be erected easily, but only so high that this strake still has 10 mm. faying-width against the expansion-ring, Fig. 13.

Before the top of the tank is lifted, a swinging-arm is fixed on it, as shown in Fig. 15. In this swinging-arm a patent-tackle is suspended and makes the erecting of the shell plates very simple; the plates may be picked up anywhere around the tank and swung into position.

When the newly erected shell strake is welded together at the vertical butts, the top of the tank is lowered carefully, and the screw-jacks permit a very exact calibration of the gap between the two shell strakes. Now the expansion-ring should be screwed out hard and the shell plates tacked on the outside. Then the expansion-ring may be lowered and prepared for the next lift, while the shell strakes are welded together inside and outside, and the same procedure is repeated until the tank is finished.

The railing on the top is welded at last directly to the "top ring". Small details as manholes, calibrator if desired, fastening for the lightning arrestor on the shell etc., are welded as the shell is lifted. Manholes etc., are preferably welded to the plates in the shop. The expansion-ring and screw-jacks must of course be of such design that they may be taken out of the tank through a manhole.

What may be said for and against this method of construction?

Well—somebody may raise the objection that the screw-jacks have to be procured, expansion-ring and swinging-arm made, and also that the lifting takes some time.

To this may be said that the screw-jacks are a "once-for-all" expense and may be used for all sizes of tanks. The expansion-ring and the swinging-arm may be used over and over again for tanks of the same diameter. In contrast to other methods, no big swinging-crane, erecting-boom or movable scaffolding are used. The time saved in erecting the shell plates and by working always at the same location close to the ground, as well as erecting of the dome at a low elevation, more than

compensates for the time spent on the individual liftings with the screw-jacks. Besides, each shop may calculate if it pays to buy jacks with electrical or hydraulic drive. We ourselves do not at present find such jacks a paying proposition.

Also, better welding is done when the welders do not have to work on more or less unsubstantial scaffolding, and a tank is produced, which —thanks to the expansion-ring—is even and exactly circular, a thing which all, who have made larger tanks, know is usually very difficult.

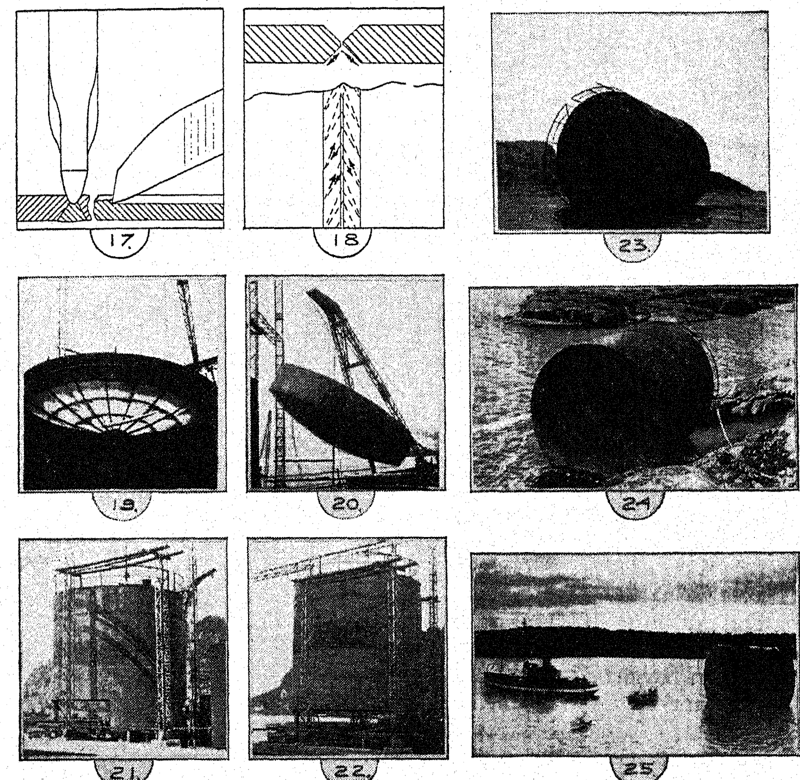


Fig. 17. Chipping chisel. Fig. 18. Oscillating manner of making vertical welds. Fig. 19. Dome fabricated upside down. Fig. 20. Dome of tank turned over. Fig. 21. Tank nearly completed. Fig. 22. Five strakes of shell in place. Fig. 23. Tank afloat after beaching. Fig. 24. Tank beached after breaking tow. Fig. 25. Tank under tow.

The method described has also a great advantage in changeable weather conditions which often prevail in this country. The inside welding of the shell is automatically protected against rain and snow and the outside welding may easily be protected by partial tarpaulins, as shown in Fig. 16.

Comparison of Costs for Welded Versus Riveted Tanks.—For such work as here described a theoretical estimate, based on footage to be welded, may be rather misleading, as many items are very difficult to calculate in advance, especially on erection work outside the shop.

However, my firm has a great deal of experience on tank construction, both riveted and welded. On May 11, this year, we sent one of the biggest oil companies in Norway alternative price on 3,000,000-litre (800,000 gallon) tanks, riveted or welded. These tanks would have to be erected some place on the South-East Coast of Norway, and I believe I am privileged to assert that these estimates are as close to the exact prices as only the backing of long experience may assure.

Presenting the figures, I have to emphasize that all welding is carried out with first class coated electrodes, and butt welds are welded also on the reverse side. This applies also to the roof plates. On bottom and shell plates, the reverse side of the welds are chipped out to such an extent that defects caused by lack of penetration are out of the question. For chipping, a chisel as shown in Fig. 17 is used. The vertical welds of the shell are welded from below upwards with relatively small electrodes, which are wielded in an oscillating manner, as outlined in Fig. 18, thereby avoiding undercutting at the sides of the weld.

All plates are cut to shape for welding or caulking by oxy-acetylene cutting machines.

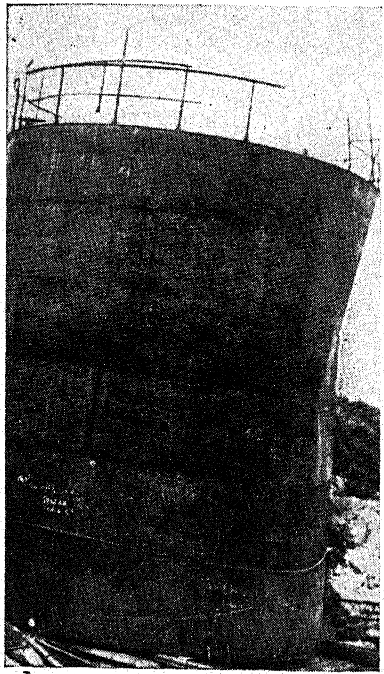
The estimate below comprises the tanks without outfit such as oil gauges, swinging pipe, ventilators, etc., but including 2 manholes, pipe studs, ladder and railing on the roof. Prices are given in Norwegian currency (4 N. Kroner to the dollar). Site of erection about 100 miles from the shop.

		Riveted: Kr.	Welded: Kr.
Steel.	87,010 kg. at 0.25	20,755	
	76,400 kg. at 0.25		19,100
Oxygen and acetylene for cutting		500	500
Electrodes			1,500
Rivets		1,310	
Screws, packing, etc.		200	200
Freight.	100 tons at kr. 12	1,200	
	90 tons at kr. 12		1,080
Return freight of tools		120	120
Fare and food.	8 men	480	
	6 men		360
Board.	8 men at kr. 6 in 90 days	4,320	
	6 men at kr. 6 in 100 days		3,600
Labor in the shop:	362 days work	4,344	
at kr. 12,—per day	300 days work		3,600
Labor on the site:	720 days work	10,800	
at kr. 15,—per day	600 days work		9,000
Total direct expenses		44,029	36,060
Written off on erecting tools		1,000	1,000
Overhead and profits		14,971	13,940
Total price to customer		Kr. 60,000	Kr. 54,000
		($15,000)	($13,500)

The above table shows a clear saving of 10% when building the welded tank, and I think everybody will agree that the welded tank has not been favoured in this estimate, rather the opposite.

The total saving to this particular country, or any other, is easy to compute when taking in account the very considerable sum of money spent each year on new tanks.

However, besides being cheaper in first cost, the welded tank has other great advantages over riveted tanks.



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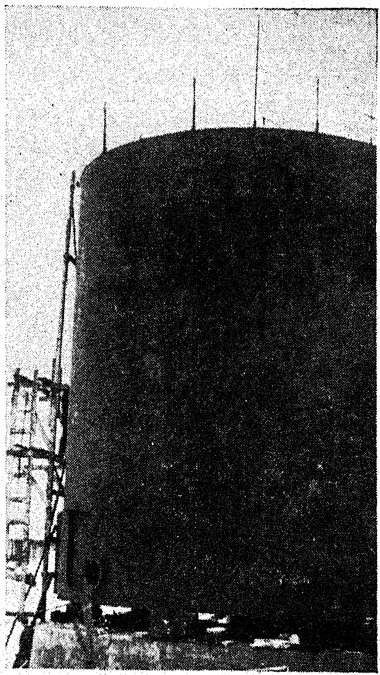

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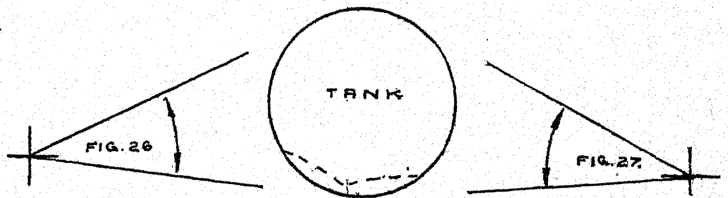

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Fig. 26. Tank dented after crashing on rocks following breaking away from tug. Fig. 27. Tank restored to original shape. Fig. 28. How photos, Figs. 26 and 27, were taken.

The clean, unbroken surfaces of welded tanks are far easier to clean, and the resistance to corroding fluids is much better, for both of which gives the welded tank a longer life. That an old riveted tank gradually shows small leaks is not unknown, but a welded tank will remain tight, assuming good workmanship.

Also, a welded tank will resist much heavier shocks or vibrations before leaking, than a riveted one. This may be of paramount importance, for instance, during a bombing attack on an oil depot, or if by accident an explosion should occur nearby.

As an example of the robustness of welded products, the following report on a welded tank, which was exposed to an accident, is quite illustrating:

A 500,000-litre, (130,000-gallon), tank was to be erected some place at the Eastern Coast of Norway, and we found it would pay to build the tank in the shop and tow it to the site. As this tank was built under an overhead crane of the shipway, the dome was built upside down and turned, Fig. 19 and 20. Fig. 21 and 22 show the tank nearly completed.

During the towing, the tug encountered such bad weather that it lost the tank, which drifted toward the shore at great speed. Eye-witnesses relate that the tank rolled over some rocks in the surface with a crash of thunder, and finally ended in the bottom of a small bay, Fig. 24. As the weather improved the tank was again set afloat, Fig. 23, and the towing continued, Fig. 25. The tank was tight. Brought ashore at its destination the tank appeared as shown on Fig. 26, but thanks to a couple of welding torches for heating and some hydraulic jacks soon resumed its original shape, Fig. 27. (Fig. 28 illustrates how the photos were taken in relation to the tank).

Chapter V—Fabrication and Erection of a Stationary Steel Tank

By E. C. Holley,
Production superintendent, St. Joseph R. R., Light, Heat and Power Co., St. Joseph, Mo.

Following the investigation and trial operation of a 300-ampere arc welder, it was purchased on or about July 10, 1936. The purchase was made in view of replacing the use of oxygen and acetylene welding, as much as possible, upon maintenance and construction work normally necessary in and around our two plants. At the time of this purchase the personnel of operators were well acquainted with gas welding and knew little or nothing about electric arc welding. Frankly, to them, the arc welder was just another generator driven by an electric motor.

The sales representative gave a course of demonstrations and trained our best man, who was a very good gas welder, to a point where the representative had confidence that this man, with more practice, would become our key man in the art of gas welding. Naturally a new piece of equipment or operation is an object of critical observation and, in watching the progress of various welding jobs, it was noted with a great deal of satisfaction the improvement each succeeding job was over the previous one. Therefore, the one-time strictly gas welder was rapidly establishing himself as an electric arc welder as well.

Although the advantages of arc welding were not new to us, the direct application and use of it in our routine maintenance and construction work was a new venture. It was during this time of adjusting the maintenance and construction personnel into applying arc welding that considerable trouble developed in obtaining a constant quality of treated water from the hot process water softening equipment at our steam plant. After numerous studies were made and various tests applied, it was found that additional sedimentation time was necessary. This meant one of two things—either changes to our present equipment or additional water-softening facilities. The first was impossible as it would require shutting down the plant for several hours and curtail service to our customers. Continuity of service is one of the prime motives of the operating department, if not the first. Therefore, we were faced with the alternative as it was imperative to provide means of properly treating the boiler water and protect the boiler equipment. Immediate steps were taken to determine the most economical and yet desirable addition as a solution to this problem. The results of these studies determined the necessity of an additional tank, (See Fig. 1), for sedimentation capacity.

Pencil sketches were hastily drawn for executive approval, indicating the location and proposed method of installation, together with a description and the reasons for such an installation. In recognition of the importance of this project immediate approval was given to proceed with the work.

From this point on the job was ours. It was up to us to see that specifications be drawn up and the field prepared for the assembly and erection of the tank. Two factors were paramount in governing this procedure. First, this was an emergency installation, one that required the utmost speed for completion. Second, railroad facilities were such that they prohibited us from purchasing a tank this size already assembled, the nearest siding being over one-half mile away. The outcome was the fabrication and erection of the tank in the field. We were conscious of the amount of welding required for this task and although our welder was as yet not a finished product, we were reasonably certain that he was equal to the job of arc welding. The results, as given by the following description, are ample proof of this.

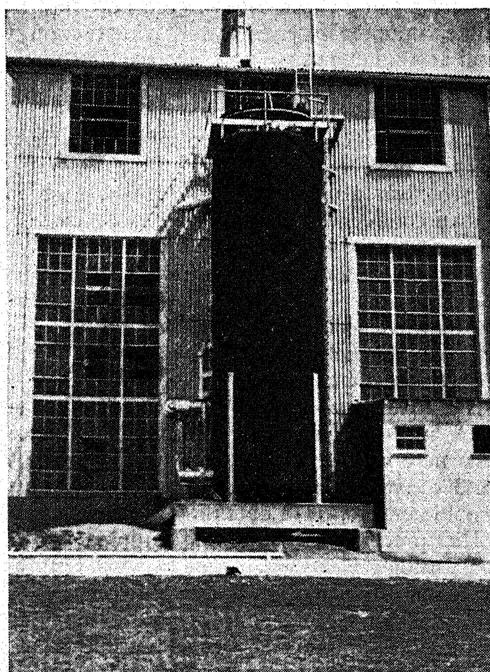


Fig. 1. Arc welded stationary tank for sedimentation.

The material for the tank was formed and shipped in sections from Kansas City and was assembled and erected by our own plant maintenance men. With the exception of having a seasoned electric welder on the job for supervision for a portion of the time no other outside labor was required. The supervisor was hired to instruct our man further in the process of electric welding, particularly with the overhead and vertical welding that was required on this job. Seventy-five per cent of the total welding requirements, however, were executed and completed by our own man who had never had an electric welding arc in his hand prior to the purchase of our arc welder.

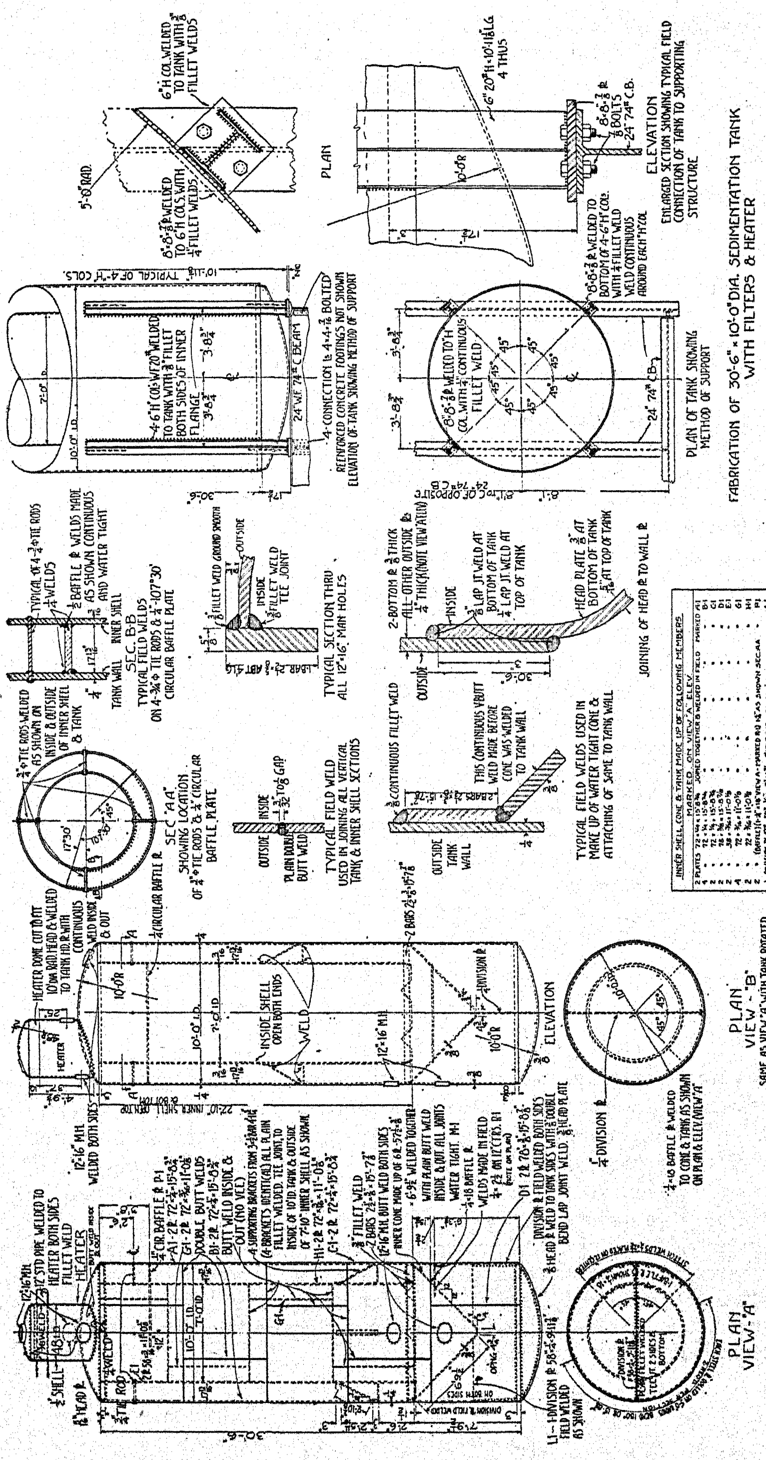


Fig. 2. Diagram of stationary tank showing details of welds.

Over ninety-five per cent of the welding was electrically done in the field and 17,652 lineal inches of three to seven layer welds were necessary. Approximately sixty-five per cent of the welding was done inside of the main tank on the inside of the sheet seams, including the fabrication of an inner tank.

The tank, on completion was given a thirty-pound hydrostatic pressure test and required only a few hours of going over the seepage leaks to make it perfectly water and pressure tight. All seams were tested with a hammer while the tank was under pressure.

It will be noted, from the fabrication diagram included in this paper, that an auxiliary heater tank was butt-welded, inside and out, to the main tank, together with 12″ welded piping connections to the auxiliary tank. All welds "Butt" on all seams. No "Vee" excepting top and bottom heads.

The following detail of welds can be found on Fig. 2 and are reported here in tabulated form:

2	Welds on 12″ Stm. Pipe = 1 weld = 3.14′. 2 = 2 x 3.14′	6.28′
3	Double welds on 3 M.H.s = 1 weld = 4′. 6 = 6 x 4′	24.00′
	Heater head & heater = 3 welds = 12.56′. 3 x 12.56′ =	37.68′
3	M.H.s in head pl. & tank = 1 weld = 4′0″ = 6 x 4′ =	24.00′
4	Tie rods in tank = 1 weld = 2¼″ = 16 x 2.25 =	3.00′
1	Baffle Pl. (Upper) = 1 weld = 13.10′ = 4 x 13.10′ =	52.60′
1	Baffle Pl. (Lower) = 1 weld =	4.00′
1	Division Plate =	34.00′
4	Hangers = 1 Bar = 21″. 4 = 4 x 21″ =	7.00′
Inner Cone	= For cone makeup 12 welds x 7′ =	84.00′
	For joining cone to tank =	94.26′
Inner Tank	= 4 Sects. 6 Welds @ 22′ (Horiz.) =	132.00′
2	Head plates = 31.41′ per weld x 4 =	125.64′
Outer tank	= 5 Sects. 8 Weld @ 31.41′ (Horiz.) =	251.28′
	Welding inner tank together (Vert.) =	91.32′
	Welding outer tank together (Vert.) =	410.00′
	Welding "H" Cols. to tank 4 @ 19.5′ =	78.00′
	Weldings Pls. to "H" Cols. =	12.00′
	TOTAL	1,470.96 Lin. Ft.
	or	
	TOTAL	17,652 Lin. Ins.

Savings.—Frankly, the savings between the two different types of fabrication and construction were of secondary importance on this particular job, the primary one being that of getting the tank in operation as quickly as possible. However, we were very fortunate in being able to apply arc welding in the field as the expansion and buckling caused by our former method of welding would have prohibited a welded job. The time saved in welding, as compared to the punch and rivet method, which would have been the alternative, is practically impossible to estimate, savings in operation and savings in direct construction being the factors. However, it is possible to portray a direct savings in fabrication and construction between the two methods.

MATERIAL AND LABOR COST AT LOCATION

Punch & Rivet Method		Electric Weld Method	
Material for Tank ....$	874	Material for Tank ....$	874
Punching	100	Electric Welding Rod	40
Caulking, 1,474′0″	268	Labor Welding Tank	128
Riveting, Approx. Rivets	100	Erection & Assembly Labor..	315
Extra Matl. in Seams for size of tank	75	Cost of Scaffold to Weld	25
Erection & Assembly Labor..	275	Cost of Electricity	75
Cost of Scaffold to Rivet	50	Fitting up done with clamps	25
No Clamps Necessary	0		
	$1,717		$1,482

Direct savings $235, or 13.69%.

After being placed in operation, the added equipment functioned properly and corrected the ills of insufficiently treated water, thereby placing the plant on a firmer basis for continued service.

Chapter VI—Arc Welded Scroll Cases for Hydraulic Turbines

By Arnold A. Seiple,
Hydraulic and mechanical engineer, Bureau of Reclamation, Denver, Colo.

In recent years many penstocks for large hydroelectric developments have been successfully constructed by means of the electric arc welding process, the Bureau of Reclamation being instrumental in the construction of the largest of such penstocks, namely those at the Boulder Power Plant. Moreover, turbine pit liners, draft tubes and liners for the discharge passages of turbine relief valves have been constructed by the electric arc process and are giving satisfactory performance in such plants as the Norris, Wheeler, Bonneville, and Boulder Power Plants. At the Bonneville plant, the turbine speed ring has been constructed by the arc welding process for the first time for large units.

Construction Materials.—Up to the present time all scroll cases which distribute water to large turbines have been constructed either of reinforced concrete, cast steel or riveted plate steel. The author of this article has made an investigation and study of the feasibility of adopting the use of the electric arc process to the construction of large scroll cases. As a result of this study, the author has included this type of construction in writing the specifications for the three 150,000 horsepower turbines to be furnished for the initial installation at the Grand Coulee Power Plant. The ultimate installation for this plant will be 18 such huge units. Each of these units will furnish 30% more power than the Boulder turbines, which are by far the largest built to date.

Due to the high head, approximately 355 feet, at the Grand Coulee Power Plant, concrete scroll cases are impractical. Not only would it be difficult to make the concrete water-tight but the placement of adequate reinforcing steel would constitute a major problem. Moreover, the head at this plant is far beyond the economic limit of approximately 100 feet for concrete scroll cases.

Cast steel scroll cases have been excluded from the turbine specifications due to the difficulty of producing sound castings of such size and weight as well as the difficulty of bolting such huge castings together.

Plate steel was therefore considered to be the only material that would meet satisfactorily the requirements of these scroll cases. Although all large plate steel scroll cases previously constructed have been riveted, the Bureau of Reclamation decided to investigate the possibilities of arc welding in this field. A study and unbiased comparison of costs was therefore made for both a riveted design and arc welded design for the plate steel cases. For the purposes of this paper, the author has gone into further detail regarding the direct costs of labor and material which follow.

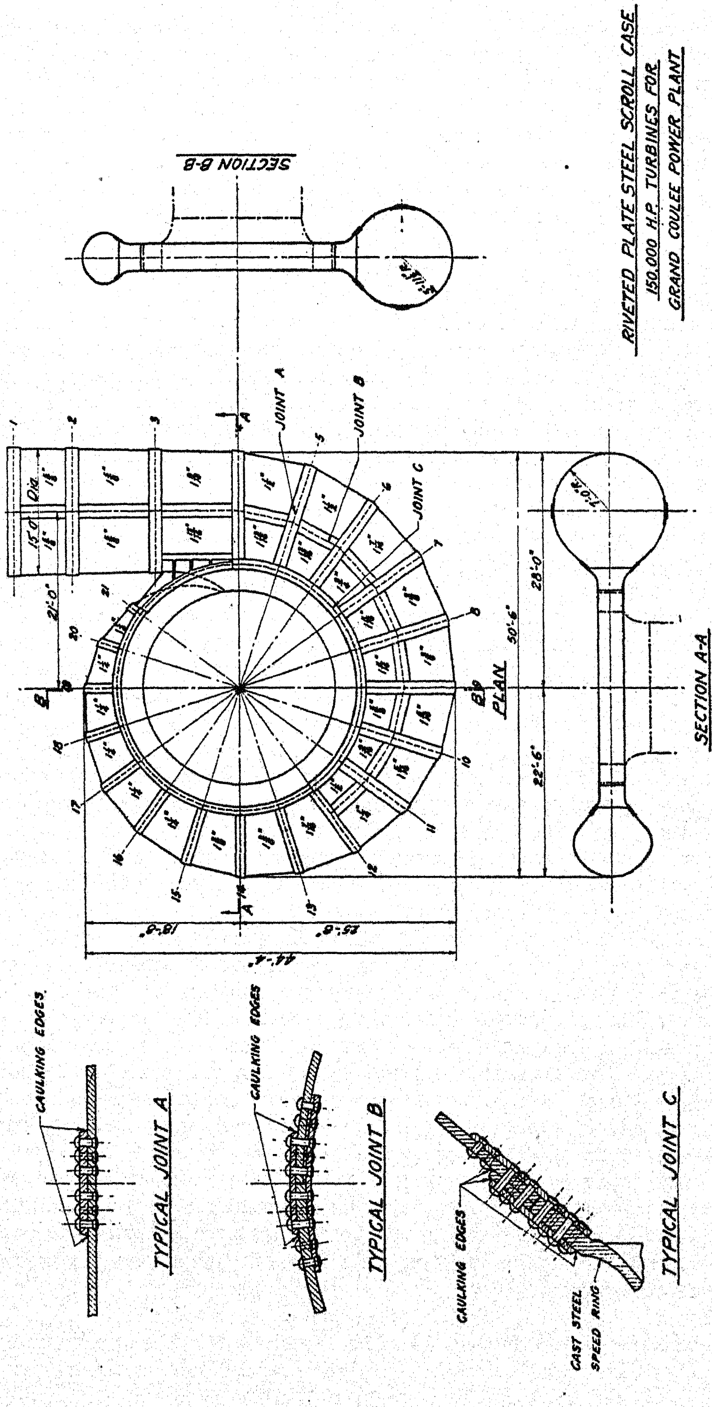


Fig. 1. Riveted plate steel scroll case.

General Layouts.—Fig. 1 shows the plan and sections on the principal center lines of the riveted scroll case. The general dimensions and the thicknesses of plates are given. Attention is called to the details of the riveted joints. Since all rivets are to be driven in the field, the size was limited to 1¼". Due to the heavy plates, it would be in the interests of economy to use larger rivets and thus increase the joint efficiencies, but practical considerations operate to restrict the size of field rivets. The circumferential joints at sections 1 to 12 are triple riveted, as shown in the detail by the typical joint A. Beyond section 12 the circumferential joints are double riveted. All circumferential joints have one butt strap on the outside of the casing. The transverse joints at the top and bottom of the scroll case between sections 1 and 12 are all quintuple riveted, as shown in detail by the typical joint B. Due to the variation in thickness of the plates on each side of the joint B, filler plates or liners are required. The joint between the scroll case and the speed ring is either quadruple or quintuple riveted, as illustrated by the typical joint C. Liners are also required at the joint C in order to make up the difference between the higher stressed plates and thicker flange of the cast steel scroll case. In order to make the casing water-tight, the outside butt straps for all joints are provided with 20° beveled edges for caulking. In typical joint C, the leading edge of the inside butt strap is beveled in order to decrease as much as possible the disturbance and friction losses of the water about to enter the speed ring. Eddy currents, however small, that may be formed at this point will be carried into the runner, thus decreasing the efficiency of the turbine and promoting cavitation. The junction of the plate steel scroll case and the cast steel speed ring, shown in typical joint C, is always a difficult joint to design and has caused much concern. By using a welded plate speed ring with a welded plate scroll case, this particular joint is greatly improved in efficiency both from the standpoint of mechanics and hydraulics. Due to the size of the scroll case, the plates will be fabricated and erected in the shop, then match marked and disassembled for shipment to the field. Therefore, all riveting and welding will be done in the field.

Fig. 2 shows the same views of the welded scroll case as shown in Fig. 1 for the riveted design. While the general dimensions are the same as in Fig. 1, the plate thicknesses are considerably less due to the perfect joint efficiencies in the welded design. Both types of scroll cases have been designed for an internal pressure of 180 pounds per square inch. The maximum allowable stress in the plates is 12,000 pounds per square inch. Since all welded joints are to be ground flush on the inside face, radiographed and stress relieved, their efficiency has been taken to be 100%. The typical joints A, B and C are drawn to the same scale as those in Fig. 1 to facilitate a visual comparison between the two types of joints. In order to produce a perfectly smooth joint on the inside of the casing, allowance has been made in the cost estimate for grinding the weld to form an even surface on the inside of the adjoining plates.

Specifications.—Following are the portions of the preliminary specifications for the 150,000 horsepower Grand Coulee turbines writ-

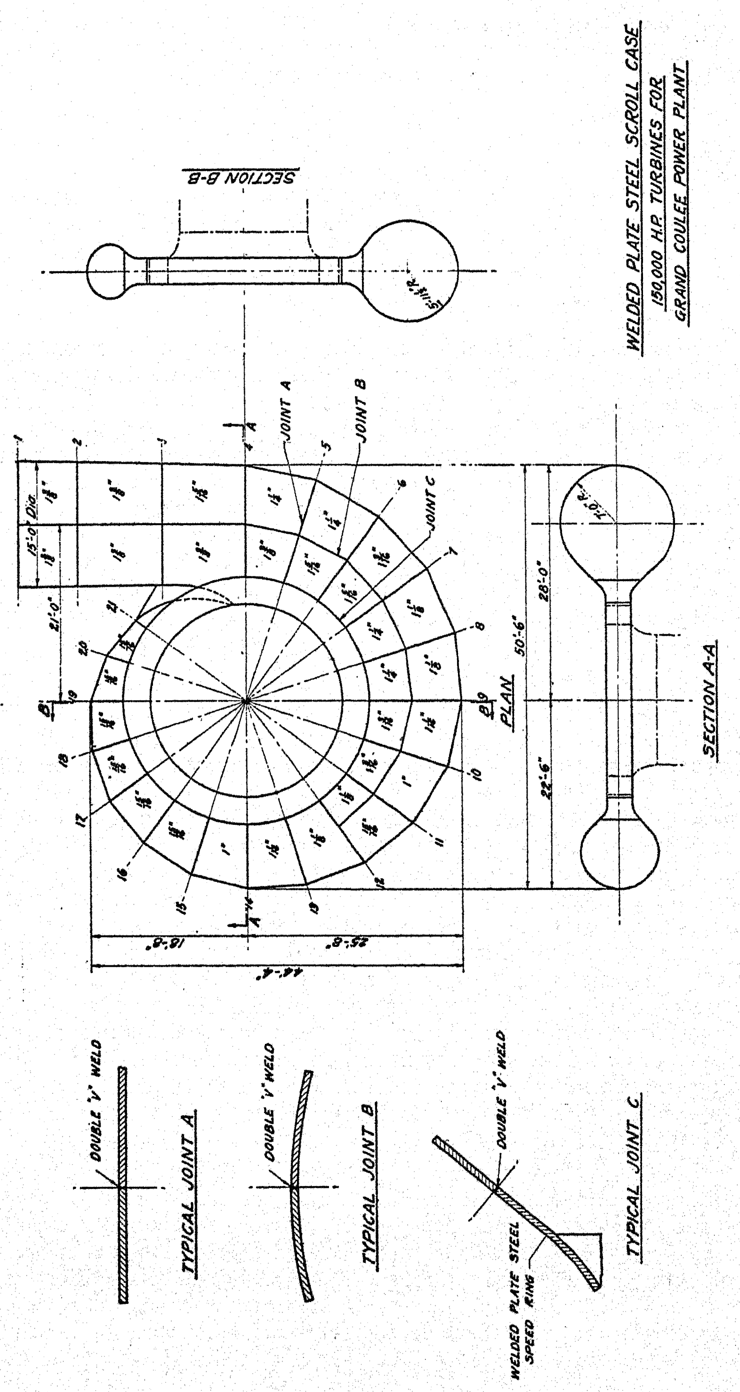


Fig. 2. Welded plate steel scroll case.

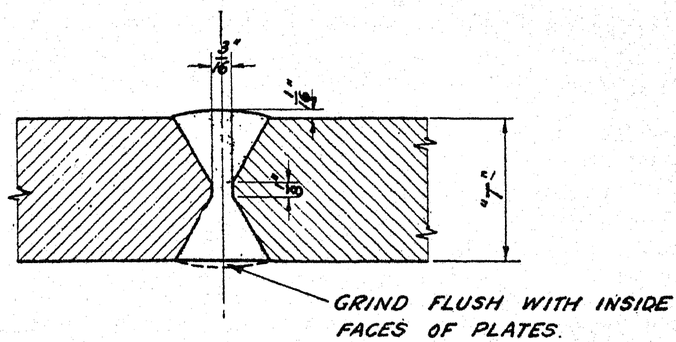
ten by the author of this article that apply to the scroll cases. This is the first time that provision has been made for welded scroll cases in the specifications for large hydraulic turbines.

1. **Steel Plates.** Steel plates for the scroll cases, speed rings, top and bottom cover plates, and pressure tanks shall be of firebox quality, grade B, conforming to the standard specifications for "Steel Plates of Flange and Firebox Qualities for Forge Welding", (A.S.T.M. Designation: A 89-33) of the American Society for Testing Materials. Steel plates for sump tanks, pit liners, draft tubes, and other unimportant stress-carrying parts shall conform to Federal specification QQ-S-711a for "Structural Steel for Bridges."

2. **Workmanship.** All work shall be performed and completed in a thorough, workmanlike manner and shall follow the best modern practice in the manufacture of high-grade machinery, notwithstanding any omissions from these specifications or drawings. All work shall be performed by mechanics skilled in their various trades. All parts shall be made accurately to standard gage, where possible, so as to facilitate replacement and repair. The contractor shall provide and maintain in storage for at least 10 years, free of cost to the Government, sufficient templates, gages, patterns, or records to enable the contractor to make repair and replacement parts. All special gages and templates necessary for field erection shall be the property of the Government, and patterns shall be the property of the contractor.

3. **Electric Welding.** (a) Preparation for welding. Members to be joined by welding shall first be thoroughly annealed, then be cut accurately to size, and, where required, shall be rolled or pressed to the proper curvature in accordance with dimensions shown on the drawings. The dimensions and shape of the edges to be joined shall be such as to allow thorough fusion and complete penetration, and plates shall be planed, if necessary, to accomplish this result. Members which are to be welded together shall be in sufficiently intimate contact at the time of welding so that the members will not be forced more closely together with the cooling of the weld, thus setting up additional strains and distortions in the weld and parent metal. The surfaces of plates to be welded shall be free from rust, grease, and scale for a distance of one-half inch back from the welding edge at the time of welding. Flame cutting may be used in the preparation of the various members, providing this operation is performed by a machine. Any contour irregularities at points of critical stress shall be removed by welding and/or grinding. Fig. 3, (top), shows detail of weld.

(b) Welding.—All welding shall be performed by the electric arc method, by a process which will exclude the atmosphere from the molten metal, and, where practicable, under precedure control using automatic machines. Welds shall have complete penetration and freedom from imperfections. Where weld metal is deposited in two or more layers, each layer shall be thoroughly peened before the subsequent layer is deposited. Where fillet welds are used, the lapped sections shall fit closely and shall be held together while the welds are being made. The finish of all welded joints shall be reasonably smooth and



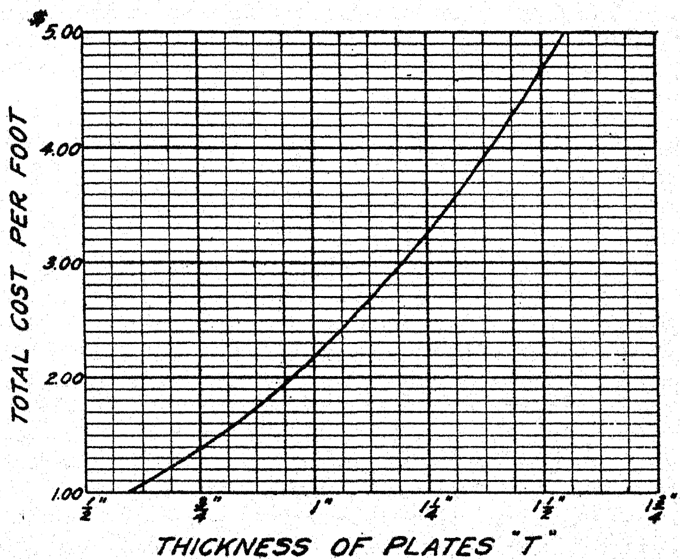


Fig. 3. Detail of weld, (top), and curve of total welding costs.

free from grooves, craters, depressions, and other irregularities. The reinforcement for butt welds shall not extend more than one-eighth of an inch above the interior surface, and, if necessary, shall be chipped or ground. All plate joints shall be either double-welded butt joints or single-welded butt joints using backing-up strips. Where single-welded butt joints are used, the root of the weld shall be chipped out to clean sound metal after removal of the backing-up strips, and a bead shall then be deposited to obtain full penetration.

(c) Stress Relieving.—All parts other than those in the draft tubes and turbine pit liner shall be stress relieved as specified in section W-462 of the "A.P.I.-A.S.M.E. Code for the Design, Construction,

Inspection, and Repair of Unfired Pressure Vessels for Petroleum Liquids and Gases."

(d) Radiographic Tests.—All welded joints between plates shall be radiographed as specified in section W-524 of the "A.P.I.-A.S.M.E. Code for the Design, Construction, Inspection, and Repair of Unfired Pressure Vessels for Petroleum Liquids and Gases."

(e) Qualifications of Welders.—The contractor shall be responsible for the quality of the work performed by his welding organization and shall employ only skilled welders who have passed the qualification tests for welders, as specified in section W-451 of the "A.P.I.-A.S.M.E. Code for the Design, Construction, Inspection, and Repair of Unfired Pressure Vessels for Petroleum Liquids and Gases." The contractor shall furnish evidence, satisfactory to the contracting officer, that all welders employed on the fabrication and erection of the turbines are qualified as required by the code, and, if the contractor cannot furnish such evidence, or if, in the opinion of the contracting officer, the work of any welder appears questionable, such welder will be required to pass a qualification test, to be made in the field, prescribed by the contracting officer.

4. Inspection and Tests. All materials furnished and all work performed shall be subject to rigid inspection, and no materials shall be shipped until all tests, analyses, and final inspections have been made or certified copies of reports of results of tests and analyses or manufacturer's guaranties shall have been accepted. As soon as practicable after receipt by the contractor of notice of award of contract, the contractor shall furnish the Government inspector five copies of each mill or shop order for materials purchased by the contractor for use in the manufacture or fabrication of the materials or apparatus to be furnished under these specifications and which will require inspection at points other than at the contractor's plant before shipment. The copies of the orders shall state the place at which the materials are to be manufactured. All such mill or shop orders shall quote the specifications for the materials to be furnished. Unless otherwise specifically provided herein, all metals covered by these specifications shall be furnished in accordance with the requirements of Federal specification QQ-M-151, "General Specifications for Inspection of Metals", which specification covers certain requirements which are common to all detail specifications for metals and provides means of determining whether the technical requirements of the detail specifications and drawings are being met. Test specimens and samples for analysis shall be properly boxed and prepared for shipment, if required. Acceptance of apparatus or the waiving of the inspection thereof shall in no way relieve the contractor of the responsibility for furnishing apparatus meeting the requirements of these specifications.

5. Shipment. In addition to the requirements of paragraph 2 all parts shall be so prepared for shipment that slings for handling by a crane can be readily attached while the parts are on the car. All parts shall be of such size and so placed on the cars as to conform to the

minimum railroad tunnel and bridge clearances encountered on the route. Boxed parts, where it is unsafe to attach slings to the box, shall be packed with slings attached to the part, and the slings shall project through the box or crate so that attachment can be readily made. Shipment by water may be required, and each bidder shall state in the blanks provided there for in the schedules, the additional cost of crating and packing the apparatus for water shipment.

6. Type and Description of Turbines. The turbines to be furnished under these specifications shall be of the vertical-shaft, single-runner, Francis type with spiral casings. Rotation of the turbines shall be clockwise when viewed looking down on the units. The spiral casings shall be of plate steel, either riveted or welded, and will be embedded in the concrete substructure of the powerhouse. Each turbine shall be designed and constructed so that all removable parts, including runners, shafts, guide bearings, guide-bearing supports, top covers, wearing rings, gate-operating mechanisms, and the wicket gates can be removed from above.

7. Head Variations. The elevation of the water surface in the reservoir will fluctuate from the maximum at elevation 1290 with the flood storage capacity completely full, to the minimum at about elevation 1208. Under present conditions, the surface of the water in the river at the dam site, with a low-water flow of 16,000 second-feet, is at about elevation 932, and with a discharge of 400,000 second-feet, the water surface in the river immediately below the dam will be at about elevation 978. The center line of the inlets to the turbine runners will be at elevation 938 and the elevation of the water surface in the tailrace will vary from about 60 feet above to about 6 feet below the horizontal center line of the turbines. The average elevation of the water surface in the tailrace will be from 5 to 10 feet above the horizontal center line of the inlets to the turbine runners. The net effective head under which the turbines will operate may vary from a minimum of about 260 feet to a maximum of 355 feet. These extreme head conditions will occur only at infrequent intervals and will be of short duration, and for 90 per cent of the time the net effective head will be between 310 and 345 feet and the average net effective head will be about 330 feet.

8. Speed Rings. The speed rings shall be of cast steel or welded plate steel and shall be designed to support the weight of the superimposed structure, including the weight of the generators, with the scroll cases empty, and also to resist the bursting stresses in the cases when subjected to an internal pressure of 180 pounds per square inch when there is no superimposed weight on top of the cases. The speed rings shall be suitably sectionalized to facilitate shipment and handling and ledges or shoulders shall be provided on the lower section of the speed ring for supporting the weight of the turbine runners and shafts

when the latter are disconnected from the generator shafts. A sufficient number of machined pads for the application of jacks and a corresponding number of suitable jacks and hold-down bolts for leveling the speed rings during erection and supporting and holding them in proper position while the concrete surrounding the speed rings is being placed, shall be provided for the speed rings. Grout holes shall be provided in the lower sections to facilitate the placing of concrete under the speed rings. If a welded design is used, all welds must be x-rayed and stress relieved. If cast steel speed rings are to be welded to the scroll cases, the steel in the speed rings must have a low-carbon content and be of weldable quality. The contractor shall make proper allowances for shrinkage during the annealing process and shall provide a motor-driven boring tool for boring the seats for the cover plates or seal rings.

9. **Scroll Cases.** The scroll cases shall be of the riveted or welded plate steel, spiral type and shall be designed for a hydro-static pressure of 180 pounds per square inch. The turbine contractor shall furnish the scroll cases complete up to a point 31 feet from the longitudinal center line of the units. The downstream ends of the penstocks will have an inside diameter of 15 feet and will be made of one and one-half inch welded steel plates. The scroll cases shall be provided with expansion joints as shown on the drawings to allow for slight movements between the dam and powerhouse. Suitable saddle flanges shall be provided on the scroll cases for connection with 10-inch pressure water supply pipes. All plates shall be annealed before they are rolled or pressed to final shape. Man doors, 24 by 36 inches in size, equipped with hinge covers and with backing-out screws, shall be provided for convenient access to the interiors of the scroll cases. The man door covers shall swing into the casings. The contractor shall drill and tap the scroll cases and/or speed rings and shall insert four fixed, bronze or stainless-steel, piezometer taps for each turbine flowmeter and four connections for each pressure gage. The details of the design and location of the piezometer taps will be furnished to the contractor. The design of the casings shall be such as to permit the removal of all internal parts of the turbines from above. The bottom cover plates and discharge rings shall be made of cast steel or welded plate steel and shall be bolted to the lower flanges of the speed rings. Renewable wearing plates shall be provided both above and below the wicket gates. The manufacturer shall provide bulkheads for closing the scroll-case inlet and speed-ring opening in order to test the scroll case under a hydrostatic pressure of 270 pounds per square inch. The test bulkheads shall be designed for attaching and removing with a minimum of field work. The scroll case will be prestressed with an internal hydro-static pressure of 145 pounds per square inch when concrete is being placed around and over the scroll case. A suitable number of supporting brackets for the application of jacks and a corresponding number of suitable jacks and lugs with hold-down turnbuckles shall be provided for supporting and holding the scroll cases in position while concrete

is being placed. All plate work, except the small parts of the casings, shall be shipped knocked-down. The scroll case shall be of such size that, with the turbine operating at rated capacity and under normal rated head, the velocity of the water at the center line of the units normal to the inlet sections will not exceed 20 per cent of the spouting velocity under a head of 330 feet. The baffle sections of the scroll cases shall be made of cast steel designed so as to eliminate the necessity for the forming of plates at the junction of the small end of the scroll case and the inlet section of the casing.

(a) Riveted Design.—The scroll cases shall be provided with circumferential butt straps for riveted connection to the penstocks. The ends of the penstocks will be left blank and will be drilled in the field to match the circumferential butt straps on the scroll cases. All plates shall be rolled or pressed accurately to proper shape to form approximate spirals. The casings and speed rings shall be assembled in the shop, and when so assembled, the plates shall be held in close contact at all points, by means of bolts. All rivet holes shall be subpunched and subreamed or subdrilled, while the plates are assembled in the shop. Reaming of holes to proper size for the rivets shall be done at the time of final assembly of the plates on all parts assembled in the factory, and will be done by the Government on all parts assembled in the field. All rivet holes shall be normal to the surface of the plates. Drift pins may be used to draw the plates into position for bolting, but the use of drift pins to enlarge rivet holes or to match unfair holes to such an extent as to distort or damage the plate adjacent to the rivet will not be permitted. All rivet holes shall be countersunk on the inside of the casing for raised-head countersunk rivets. All plates shall be matchmarked to facilitate assembly in the field. After the casings are disassembled, all burrs left by the reamers or drills shall be removed. All caulking edges on plates and butt straps shall be properly beveled, and the distance from the center line of the nearest row of rivet holes to the edge of the plates or butt straps shall be one and three-quarters times the diameter of the rivet. Rivets for field erection shall be furnished in the amount of 10 per cent in excess of the actual number of each size and length required. Sufficient fitting-up bolts shall be furnished for field erection to permit all plates to be held in close contact while being riveted. The number of fitting-up bolts of all lengths furnished with the casing and inlet pipe to be furnished under these specifications shall be not less than 25 per cent of the total number of rivets required for the complete scroll cases, including the connection to the penstock.

(b) Welded Design.—All plates shall be rolled or pressed accurately to shape to form approximate spirals. The edges of all plates shall be properly prepared for welding. The casings and speed rings shall be assembled in the shop and when so assembled the plates shall be held in close contact at all points by means of bolts. All plates shall be

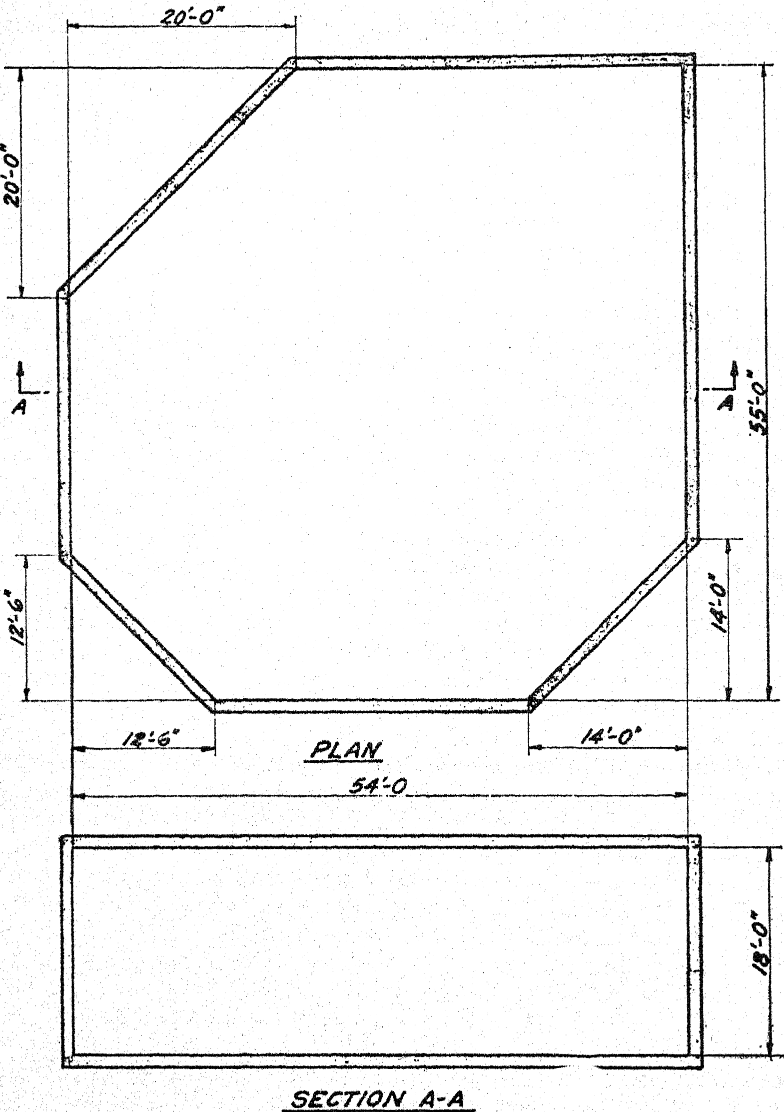


Fig. 4. Annealing oven.

match-marked while assembled in the shop. The field assembly welding, and fitting of all machined surfaces, shall be done by the manufacturer. After welding, the contractor shall remove all bolts used in assembling the casing and shall fill the bolt holes by welding. All welds shall be x-rayed and the entire scroll case shall be stress-relieved by the manufacturer. For this purpose an annealing oven, (See Fig. 4), will be provided by the Government in the pit for unit L-9. Suitable

stiffeners and lugs for slings shall be provided for moving the scroll case and speed ring from the annealing oven to the final position. The contractor shall weld the connection between the scroll case expansion joint, furnished by him, and the penstock. This welded joint shall be x-rayed but not annealed. The contractor shall make proper allowance for shrinkage during the annealing process and shall provide a motor-driven boring tool for boring the seats for the cover plates and the seats for the stationary wearing rings.

Cost of Riveted Scroll Case.—From the unit costs and quantities for the riveted scroll case, the various items are collected and extensions made in the following table, which shows the total installed cost of the riveted scroll case to amount to $59,017.54. The total cost per pound is $ .1507. Fig. 3, (bottom), shows curve of total welding costs.

COST OF RIVETED SCROLL CASE

Item	Quantity	Unit	Unit Cost	Cost of Item
Plates	272,330	lbs.	$ .095	$25,871.35
Butt Straps	119,310	lbs.	.095	11,334.45
Drilling Holes	43,016		.054	2,322.86
Countersinking Holes	16,662		.026	433.21
Reaming Holes	16,662		.040	666.48
Beveling Edges				1,055.42
Field Erection	391,640	lbs.	.010	3,916,40
Riveting	16,662		.480	7,997.76
Caulking Edges	2,013	ft.	.124	249.61
Shipping Charges	470,000	lbs.	.011	5,170.00
TOTAL COST				$59,017.54

Cost of Welded Scroll Case.—From the unit costs and quantities for the welded scroll case, the various items are collected and extensions made in the following table, which shows the total cost before annealing to be $29,550.70, which is very close to half the total cost of the riveted scroll case. The total cost of the welded scroll case after annealing amounts to $31,475.70. The total cost per pound is $ .1465.

COST OF WELDED SCROLL CASE

Item	Quantity	Unit	Unit Cost	Cost of Item
Plates	214,830	lbs.	$ .095	$20,408.85
Drilling Holes	1,290		.046	59.34
Beveling Edges				586.50
Field Erection	214,830	lbs.	.010	2,148.30
Welding Joints				2,641.38
Welding Holes	1,290		.294	379.26
Grinding	882	ft.	.111	97.90
Radiographing	882	ft.	.446	393.37
Shipping Charges	257,800	lbs.	.011	2,835.80
Sub-total				$29,550.70
Annealing				1,925.00
TOTAL				$31,475.70

Proportionate Savings Due to Welding.—According to the itemized costs previously shown, the total cost of the riveted scroll case amounts to \$59,017.54. The weight of all plates and butt straps amounts to 391,640 pounds. From the costs for the welded layout, the cost of the unannealed scroll case is \$29,550.70, and the cost of the annealed scroll case amounts to \$31,475.70. The weight of the plates for the welded casing is 214,830 pounds. The saving for the welded scroll case, if annealed, amounts to \$27,541.84, which is 46.7% of the cost of the riveted design. This saving will be increased to \$29,466.84 or 49.9% should it be decided that annealing is not necessary. The saving in weight amounts to 176,810 pounds, which is 45.2% of the weight of the riveted scroll case. The unit cost for the riveted scroll case amounts to \$ .1507 per pound, while the same costs for the welded scroll case amount to \$ .1465 for the annealed casing and \$ .1375 for the unannealed casing. Annealing the scroll case adds 6.5% to the cost of the welded casing.

Due to the double curvature of the scroll case and the possibility of high residual stresses, the cost of the welded casing will be taken at the higher figure which includes stress relieving. On this basis the saving in cost for the first three scroll cases for the Grand Coulee power plant will amount to 3 x \$27,541.84 or \$82,625.52 for the initial installation.

Gross Savings Accruing to Industry.—Foundations are in place at the Grand Coulee power plants for eighteen 150,000 horsepower turbines. Should the welded design of scroll case be adopted for the initial installation of three units, it would naturally follow that all the remaining units would be provided with welded scroll cases. The saving accruing from welding the entire eighteen scroll cases would amount to 18 x \$27,541.84 or \$495,753.12. Thus the saving in direct cost for this one power development alone amounts to almost one-half million dollars!

Foundations for twelve 65,000 horsepower pumps are to be placed at Grand Coulee for the pumping plant adjacent to the left power plant. Since the discharge casings for these huge pumps will be somewhat similar to the scroll cases for the turbines, these casings would also be welded. The savings for the twelve welded pump casings, based on the savings for the turbine scroll casing, would amount to

$$\$27{,}541.84 \times \frac{12 \times 65{,}000}{150{,}000} \text{ or } \$143{,}217.57.$$

The power requirements for station service call for the installation of three 14,000 horsepower units in the left power plant. Two 14,000 horsepower turbines will be installed at the same time that the three initial 150,000 horsepower turbines are installed. The savings due to welding the scroll cases of all three station service units amounts to

$$\$27{,}541.84 \times \frac{3 \times 14{,}000}{150{,}000} \text{ or } \$7{,}711.72.$$

The total direct savings accruing from the welding of all turbine and

pump casings amounts to the grand sum of \$646,682.41 as shown by the following tabulation:

Item	Number	Amount of Savings
150,000 H.P. Turbine Scroll Case	18	\$495,753.12
65,000 H.P. Pump Casing	12	143,217.57
14,000 H.P. Turbine Scroll Case	3	7,711.72
TOTAL		\$646,682.41

Within a short time construction will be started for the Shasta dam and power plant in California. This plant is to have an ultimate installation of five 100,000 horsepower turbines of which four units are to be installed initially. The savings accruing from welding the scroll cases for all five turbines amounts to

$$\$27{,}541.84 \times \frac{5 \times 100{,}000}{150{,}000} \text{ or } \$91{,}806.13.$$

The proposed development of the St. Lawrence River for both power and navigation in the vicinity of Croil Island in the international section of the river, calls for a total installation of 2,500,000 horsepower. The savings accruing from the installation of welded scroll cases in place of riveted casings for this development would save approximately \$500,000.00, based on the savings from the Grand Coulee welded scroll case. Since the power that could be developed from the entire St. Lawrence River is six times as great as the proposed development, the savings that would accrue are figured to be around \$3,000,000.00 from the harnessing of the entire river.

The direct savings that would accrue by welding the scroll cases for all future developments would amount to tens of millions of dollars.

Savings from Increased Efficiency.—Besides the huge direct savings in the initial costs obtained from installing welded scroll cases in place of riveted casings for hydraulic turbines, there is also a very substantial indirect saving due to the greater hydraulic efficiency of the smoother welded casings. The amount of power saved by welding the scroll case for one of the 150,000 Grand Coulee turbines is based on Fred C. Scobey's formula

$$H = K\frac{V^{1.9}}{D^{1.1}} \text{ in which}$$

H = head in feet lost per thousand feet of conduit
K = a coefficient based on experience for the particular type of conduit selected
V = average velocity through the conduit in feet per second
D = diameter of conduit in feet

Since the turbines will be shut down for annual inspection and maintenance, the coefficients selected are for new conduits since the scroll cases are of sufficient size to permit the entrance of workmen to recondition the inside surfaces and remove obstructions when required. The coefficients selected from "The Flow of Water in Riveted Steel and Analogous Pipes" by Scobey are K = .48 for the riveted scroll case and K = .32 for the welded scroll case. Friction head losses,

H, have been calculated and are recorded in the following table for several sections of the scroll case when the turbine is discharging 4800 cubic feet per second, which is the designed capacity.

FRICTION LOSSES IN SCROLL CASES

Section	Diameter D	Area sq. ft.	Discharge c. f. s.	Velocity V	H, head loss per 1000 ft. K = .48	K = .32
1	15.00	176.8	4800	27.15	12.93	8.62
4	14.00	154.0	4400	28.55	15.36	10.24
9	11.93	112.0	3200	28.55	18.32	12.21
14	9.45	70.1	2000	28.55	23.65	15.76
19	5.97	28.0	800	28.55	39.20	26.14

On the basis of the calculated head losses in the above table, the actual losses for the segments between the sections are tabulated for both the riveted and welded scroll cases in table below. The average discharge in the segments and the increase in power by using the welded scroll case in place of the riveted casing are also listed. The total increase in power by using the welded scroll case amounts to 238.2 horsepower. Inasmuch as the same diameters, radii of curvature and number of cuts occur in both casings, the bend losses are assumed to be identical.

Although the increase in the power output of the turbine when operating at capacity is calculated to amount to 238.2 horsepower or 0.16%, the average increase will amount to considerably less due to the fact that the turbine will not be operated at capacity at all times. On the assumption that the turbine will normally be operated between seven-tenths gate opening and full gate opening, the increase in power output will range between 82.0 and 238.2 horsepower. An average increase in output will be conservatively taken as 120 horsepower.

INCREASE IN POWER OUTPUT

Segment	Av. Length ft.	Actual Loss in ft. K = .48	K = .32	Diff. in Head Losses	Av. Discharge	Increase in Power H. P.
1–4	27	.382	.255	.127	4725	60.0
4–9	32	.539	.359	.180	3800	68.4
9–14	30	.630	.420	.210	2600	54.6
14–19	27	.840	.560	.280	1400	39.2
19–21				.400	400	16.0

TOTAL INCREASE IN HORSEPOWER.................................238.2

Taking the value of power to be approximately 3 mills per kilowatt-hour or $20.00 per horsepower-year, the value of the increase in power due to welding the scroll case amounts to 120 x $20.00 or $2,400.00 per annum. This annual saving represents a far greater capital investment. The following capital charges are taken as a basis for further calculations.

Interest on investment ....4% per annum
Depreciation ....2% per annum
Maintenance ....1% per annum

Total capital charge ....7% per annum

This annual saving of $2,400.00, when capitalized at 7%, becomes $34,285.71. Thus, the indirect saving, due to an average increased efficiency of only 0.08%, is greater than the saving in first cost which amounts to $27,541.84. The capitalized value of the increase in power, plus the saving in first cost, amounts to $61,827.55. This is 105% of the first cost of the riveted scroll case. In other words the total direct and indirect savings, accruing from the installation of the welded scroll case in place of the riveted casing, exceeds the first cost of the riveted casing by 5%.

The capitalized value of the increased power amounts to approximately 125% of the direct saving in first cost. Thus the total saving for the Grand Coulee development would amount to approximately $646,682.41 x 125% or $808,353.01. This saving, due to increased efficiency plus the saving in first cost, amounts to the grand total of $1,455,035.42 if welded casings are installed throughout the Grand Coulee development. Since the total installed horsepower for all turbines and pumps is to be 3,522,000 horsepower, the total savings amounts to approximately $0.41 per horsepower.

According to the Interim Report of the Federal Power Commission for the year 1935, the total undeveloped hydro power available in this country amounted to 52,628,900 kilowatts. Deducting the amount of water power developed since this report was made, the amount of power undeveloped today is approximately 70,000,000 horsepower. Of this amount it will be assumed that 20% will be produced by low head developments that will not require steel scroll cases. Therefore, approximately 56,000,000 undeveloped horsepower in this country alone are within the field for welded plate steel cases. On the basis that a saving of $ .40 per installed horsepower will accrue from both first cost and increased power output, the total saving that can be obtained in this country by the general adoption of welding to plate steel scroll cases amounts to $22,400,000.00. The amount that can be saved by the adoption of welded scroll cases throughout the civilized world would be several times this figure and amount to well over $100,000,000.00.

Better Performance.—Due to the absence of rivets and caulked edges, the possibility of leakage is reduced to a negligible factor. Moreover, the smoother interior, besides reducing friction losses and thereby increasing the efficiency, will check the formation of eddy currents. This in turn will promote smoother operation of the turbine as a whole due to lessened vibration and cavitation.

Increased Service Life.—Since the entire scroll case will be embedded in concrete, the exterior will be inaccessible. Therefore, any leakage through the casing may cause unchecked corrosion on the exterior. With the use of the welded casing, this cause of corrosion is eliminated due to the absence of leakage which may occur in the riveted construction. Although all rivets will be countersunk on the inside, the heads would be raised slightly. Due to the high velocity of the water in the scroll case, over 28 feet per second, cavitation may be caused due to the water impinging on the rivet heads and butt straps. By adopting the welded construction, not only is the efficiency

of the scroll case increased and the possibility of cavitation therein materially reduced, but the same effects are projected into the runner. The relatively smooth entrance from the scroll case to the speed ring, besides reducing friction, will check the formation of eddy currents normally created at this point by the riveted construction. These eddy currents are carried into the runner and have a decidedly bad influence on the efficiency of the turbine and induce destructive cavitation. Thus, by checking the formation of eddy currents, the destructive cavitation will be reduced not only in the scroll case but in the turbine runner as well. The useful life of the unit, therefore, will be materially increased.

Social Advantages.—The principal social advantage gained by the general adoption of welding to the fabrication of turbine scroll cases lies in the conservation of natural resources. Due to the great reduction in weight, 45.2%, the natural resources of iron, coal, limestone, etc., will be conserved to a similar extent. Moreover, the labor required to produce the finished casing would be reduced by approximately 50%, as reflected in total first costs.

By increasing efficiency and thereby producing more power, society in general will benefit by the conservation of the water power that would otherwise be wasted in the less efficient riveted scroll case.

The elimination of the noise caused by the riveted construction will be a relief to the large number of men engaged at other tasks during the construction of a hydro-electric power plant.

Chapter VII—A Pipe Line for Steel Mill Service

By HOWARD WEISS,
Engineer, The Dingle-Clark Co., Cleveland, Ohio.

Modern high speed steel mills contain a heavy concentration of rotating electrical machinery. Mill motor rooms are provided with the largest electric motors used in industry. Usually these motors are the direct-current type and are fed from motor generator sets in the same room.

These large machines are all cooled by forced currents of air, so that their size will be within limits economical for construction, transportation, and operation. So important is this forced-draft cooling that, in the air ducts, air flow relays are provided to shut down the machines if the air supply fails. Otherwise, the machines would quickly burn up due to the large electric currents involved in their operation.

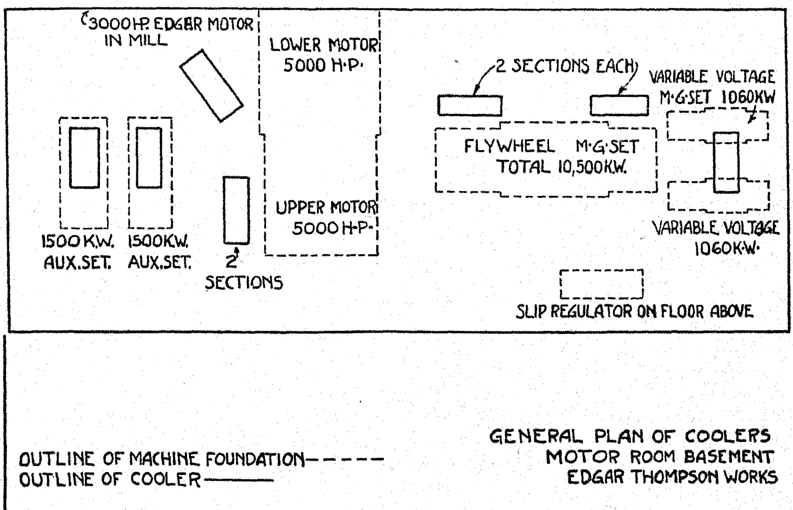


Fig. 1. General plan of coolers.

The heart of the cooling system is a finned water tube cooler which removes heat from the air forced through the machines. Only a small percentage of outside air enters the circulatory system and the same air is used over and over again.

The importance of a reliable, long-lived, piping system to supply the large quantity of water required by the coolers can not be overestimated. Failure of the water system results in costly shutdowns of the mill whose earning power is dependent on long periods of continuous operation.

The writer participated in the design of the water piping system for the air coolers used in the slabbing mill of the Edgar Thomson Works of the Carnegie-Illinois Steel Co. at Braddock, Pa. This mill will supply the slabs for that company's new strip mill being built at Irvin, Pa.

Function of Piping System.—The piping system to be described supplies water to the coolers shown in the diagram, Fig. 1. Requirements for these coolers and their characteristics are given in Table I. The system also supplies 40 G.P.M. of cooling water to the slip regulator which controls the 7500 H.P. wound rotor induction motor driving the flywheel m.g. set.

TABLE I.—COOLER CHARACTERISTICS

Machines to be Cooled	Number of Sections	Gallons Per Minute Required, Max.	Pressure Drop Lb./Sq. In. Each Section	Position of Nozzles
2 Variable Voltage MG Sets	1	410	3.03	Vertical
Flywheel MG Set	4	1950	5.41	Horizontal
Main Drive Motors	3	1550	5.84	Horizontal
2—1500 KW Aux. Sets	2	600	2.81	Vertical

The system must be designed to supply the designated flow of water to the coolers shown in the diagram. The Carnegie-Illinois Steel Co. provides the piping up to the motor room basement. This paper will discuss the design of the piping from that point to the coolers and the return line back to the general mill system.

Factors Considered in the Design.—A–COST.—A new steel mill is such a large project that, to speed construction, contracts are frequently let before all the details are on paper. Such is the case with the Edgar Thomson slabbing mill. A price for this piping system was determined before the complete layout of the coolers was supplied by the owner. The price was based on an estimate made with the information available, such as number and approximate capacity of coolers.

Actual design was not begun until specific details were available. These included friction loss through each cooler, location of coolers, and position of basement obstructions, such as machine foundations, bus structures, and building steel. Then the system was designed to meet the contracted requirements and produce a legitimate profit, if possible, for the contractor. Since the allowable cost was limited by the predetermined price, any methods that would do the job well and save money warranted consideration.

The original price demanded a very careful design. Obviously, a large number of pipe sizes would satisfy the technical requirements. However, the cost of the job increases with the size of pipe, so the design must utilize the smallest possible sizes of pipe. Fittings and

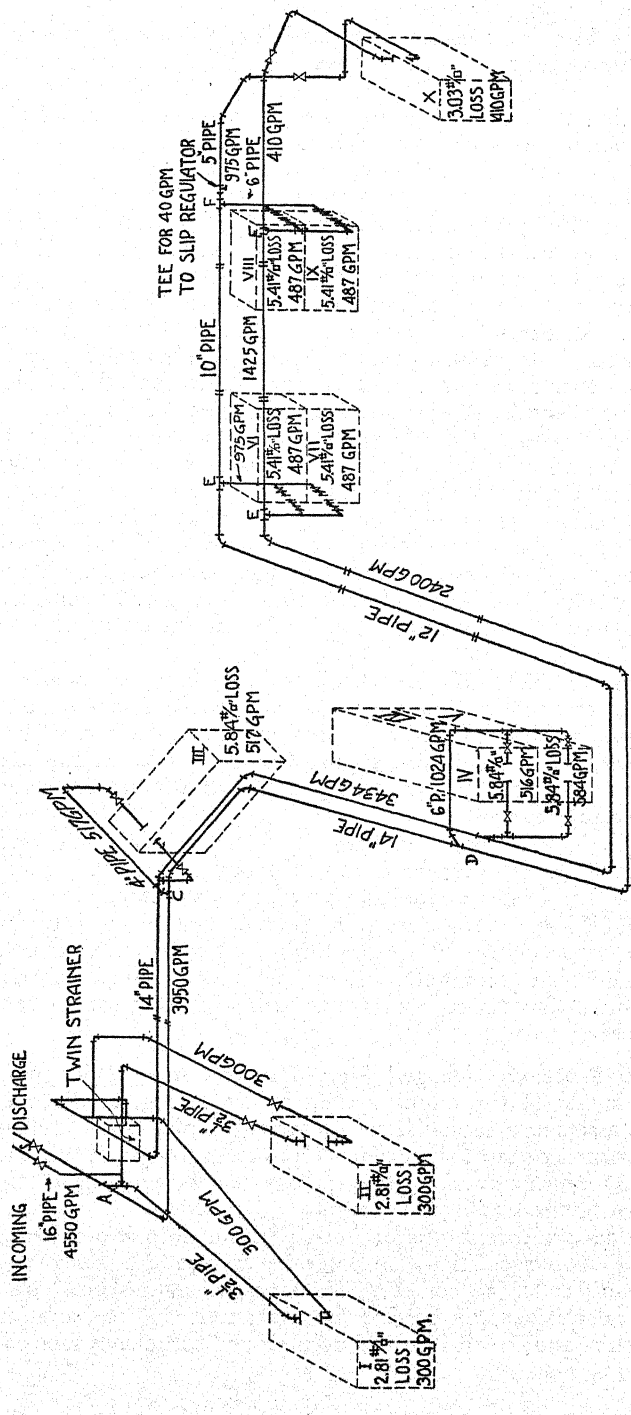


Fig. 2. Schematic diagram of flanged water cooler system.

accessories, likewise, must be kept small in size. Any construction features which reduce the number of fittings will, of course, reduce the cost.

Any elimination of fittings must be done without increasing the cost of the labor or the saving would be nullified. The sum of the material and labor must be used in comparing designs since these are the variable cost factors.

B–FRICTION LOSS.—The contract specifies that the owner shall supply raw water at a pressure of 20 pounds per square inch. The motor room piping system must return the water to the general mill system at not less than 5 pounds per square inch. The maximum tolerated friction loss of 15 lbs. per sq. in. will be one limiting factor in determining the pipe size. This pressure drop includes the coolers themselves. Since the motor room basement is crowded with equipment, the system will involve short lengths of pipe and a large number of fittings.

The best system is that providing the smoothest flow of water, thus minimizing turbulence which constitutes so large a part of the friction loss. Changes in flow should be gradual instead of abrupt.

C–SPACE.—The pipe system must be located in the space not occupied by machine foundations, bus structures, or other equipment in the basement. Routing of the pipe will be affected by the sheet metal air chamber enclosures. Headroom is an important consideration since maintenance work must be done on all the equipment in the basement.

D–MAINTENANCE OF PIPES.—This factor was not included in the cost of the pipe line since the costs to be discussed are only those borne by the contractor. However, maintenance must be considered in order to secure the approval of the owner of the mill. A large maintenance cost reflects a poor design and increases the annual cost of the piping.

E–DELIVERY.—Only standard methods and materials available on reasonable notice could be used in the design since the completion date set by the owner limited the time of construction.

F–VELOCITY.—Pipe sizes were limited primarily to those which delivered the necessary gallons per minute of water at a velocity not exceeding 600 feet per minute. In very short runs such as the branches to the coolers, this figure can be exceeded without harm or error in friction loss.

Design Procedure, Flanged Job.—The first step in design is the isometric layout of the piping system shown in Fig. 2. Each cooler section is assigned a capital letter. Routing of pipe is dictated partly by the obstructions in the basement. Pipes must go around the machine foundations which extend up to the floor, and be underneath the extensive bus system feeding the motors.

Pipe sizes are determined by both pressure drop and velocity calculations. These calculations are necessary to meet the previously outlined conditions of the contract. Conservative figures only are used since no calculations can predict the exact loss, due to variations in workmanship, and the change of roughness and turbulence factors with age of equipment.

Table II—Computation of Pressure Drop—All Flanged Job

Run	Pipe Size	Number 90° Ells	Equivalent Length of Ells	Number 45° Ells	Equivalent Length of 45° Ells	Number of Tees	Equivalent Length of Tees	Number of Valves	Equivalent Length of Valves	Number of Reductions & Expansions	Equivalent Length of Red. & Exp.	Actual Length Feet	Total Equiv. Length Feet	Gallons per Minute	Pressure Drop Lb/Sq. In.	Velocity Ft/Sec.
F-X	5″	5C	70	1	9			2	6	{2, 5-6 {2, 10-5	26	90	201	410	3.1	6.7
Ft	10″					2	34					34	34	410	0.01	
IX-VIIIt	6″	2	32			2	22	2	7			12	73	487	0.66	5.5
VIII-VIIIt	6″					2L	68	2	7			4	79	487	0.71	5.5
VIIIt-F	6″									2, 10-6	10	5	15	975	0.48	11.0
FtL	10″					2L	90					0	90	975	0.22	
EF	10″									2, 12-10	10	100	110	1425	0.57	5.8
Et	12″					2	40					0	40	1425	0.06	
VII-VIt	5″	2	28					2	6	4, 5-6	12	12	58	487	1.30	7.9
VI-VIt	5″							2	6	4, 5-6	12	4	22	487	0.48	7.9
VItL	6″					2L	56					0	56	487	0.51	
VIt′	6″					2	22					0	22	487	0.20	
VIt-E	6″									2, 10-6	10	5	15	975	0.48	11.0
EtL	10″					2L	90					0	90	975	0.22	
DE	12″	2	64	4	80					2, 14-12	12	208	364	2400	1.87	6.8
Dt	14″					2	48					0	48	2400	0.15	
V-IVt	5″	2	28					2	6	4, 5-6	12	12	58	517	1.4	8.4
IV-IVt	5″							2	6	4, 5-6	12	6	24	517	0.59	8.4
IVtL	6″					2L	56					0	56	517	0.56	
IVt	6″					2	22					0	22	517	0.12	
IVt-D	6″	2	32							2, 14-6	14	15	61	1034	2.17	11.7
DtL	14″					2L	156					0	156	1034	0.11	
D-C	14″			4	92							66	158	3434	1.1	8.0
CtL	14″					2L	156					0	15	516	0.03	
Ct	14″					2	48					0	48	3434	0.33	
C-III	4″	4	44					2	4	{2, 4-6 {2, 14-4	20	22	90	516	6.68	13.1
A-C	14″	2	72							2, 16-14	10	76	158	3950	0.11	9.2
A-II	3½″	5	70			2L	40	2	4	{2, 3½-6 {2, 16-3½	14	53	181	300	9.9	10.0
A-I	3½″	4	38			2	12	2	4	{2, 3½-6 {2, 16-3½	18	24	96	300	4.32	10.0
AtL	16″					2L	180					0	180	600	0.21	
At	16″					2	54					0	54	3950	0.02	
A-S	16″	4	168					2	18			20	206	4550	1.07	7.2

Note: t = tee at that point or directly opposite point
L = run through branch of tee
C = Cast iron fitting
B = Bend
W = Welding ell

Each run of pipe, its fittings, friction loss, and velocity were then listed in a table similar to Table II except that 3 or more pipe sizes for each run were listed. The smallest pipes that would do the job were then selected. Consideration was also given the number and cost of fittings. Selection of pipe was made and friction loss tabulated similar to Table III. A total pressure drop of 15 lbs. per sq. in. was permitted.

Explanation of Tables II and III.—Table II shows the calculation of friction loss in the pipes finally selected as mentioned above. The friction loss is:

$$\text{Loss (lbs. per sq. in.)} = \frac{(\text{G.P.M.})^{1.86} \times L}{1435 \times D^5}$$

Where: G.P.M. = Gallons per minute.
L = Total equivalent length of straight pipe in feet.
D = Inside diameter of pipe, inches.

The total equivalent length of straight pipe is the sum of the actual length plus the equivalent length of the fittings. This method assumes the fittings have no length.

Sample calculation:

Referring to Fig. 2, the run D to E of 12″ pipe has 2–90° ells and 4–45° ells. Including the return pipe, the run is 208 feet long, as scaled from Fig. 4. The run does not include the tees at D or E. These are figured separately since the gallons per minute in the run is different than in the branches, and the tee at D is 14″ while the run D–E is 12″ pipe. There are also 2 abrupt changes in diameter from 14″ to 12″. The equivalent lengths for this loss and the elbows are taken from Table IV. Their sum and the actual length is:

$$L = 2 \times 32 + 4 \times 20 + 208 + 2 \times 6 = 364 \text{ Feet}$$

Since the quantity of water is 2400 G.P.M., the loss is:

$$\text{Loss} = \frac{(2400)^{1.86} \times 364}{1435 \times 12^5} = 1.87 \text{ lbs. per sq. in.}$$

The velocity is calculated by the conventional hydraulics formula:

$$\text{Velocity} = \frac{(\text{G.P.M.}) \times 0.408}{D^2} = \frac{(2400) \times 0.408}{12^2} = 6.8 \text{ Ft. per sec.}$$

Note that to be conservative the 40 G.P.M. for the slip regulator is included in both pipes.

Referring to Table III, the pressure head across each pipe circuit is totalled to determine the worst pressure drop in the system. Starting at the farthest cooler, X, the pressure drop from point F to this cooler is the sum of losses through the cooler, the run F-X, and the tee at F. At this point the branch to coolers IX and VIII is brought in. The top of the middle and right hand columns sums the losses to a point just above the tees in front of cooler VIII. The loss in the branch from VIII is greater than from IX, so to the larger loss is added the drop to point F.

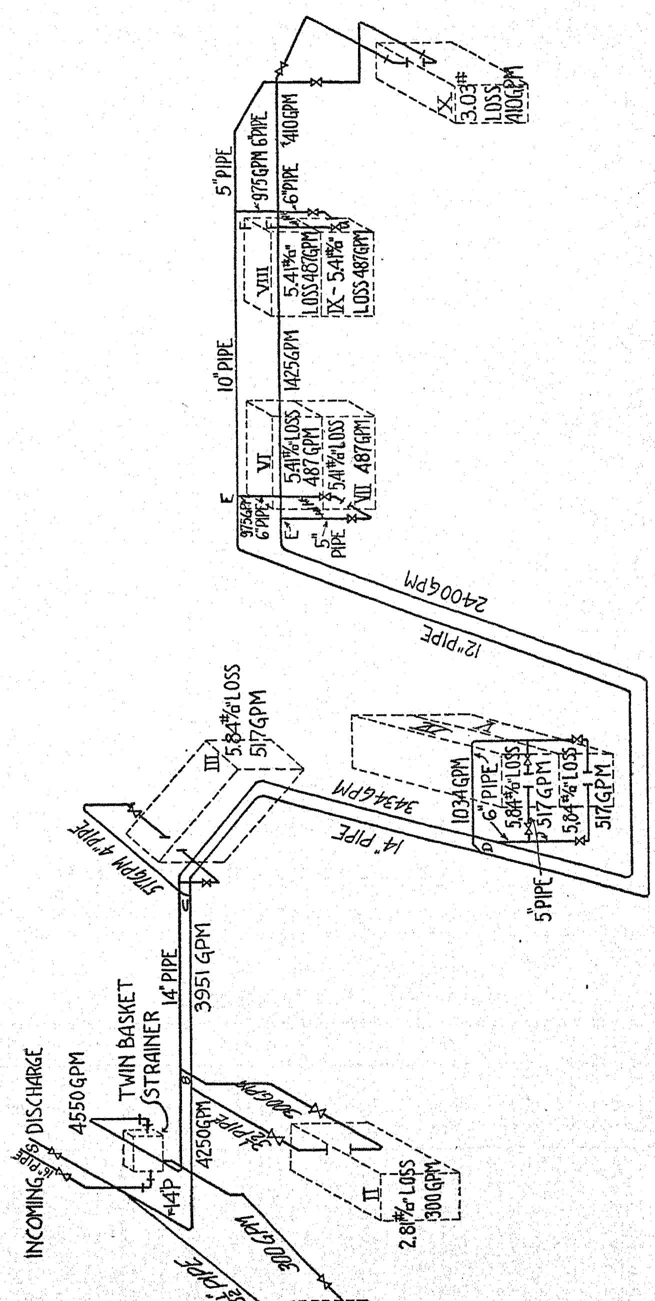


Fig. 3. Schematic diagram, arc welded and flanged system.

TABLE III—SUMMARY OF PRESSURE DROPS FLANGED JOB

Run Loss	Run Loss	Run Loss
X–3.03	IX–5.41	VIII–5.41
F–X–3.1	IX–VIIIt–0.66	VIII–VIIIt–0.71
Ft–0.01		
	VIIIt–6.07	VIIIt–6.11
F–6.14		VIII–F–0.48
	VI–5.41	FtL–0.22
VII–5.41	VI–VIt–0.48	
VII–VIt–1.30	VItL–0.51	F–6.81
		E–F–0.57
VIt–6.71	VIt–6.40	Et–0.06
VIt–E–0.48		
EtL–0.22	V–5.84	E–7.44
	V–IVt–1.40	D–E–1.87
E–7.41	IVt–0.12	Dt–0.15
xxxxxxxxxxxx		
IV–5.84	IVt–7.36	D–9.46
IV–IVt–0.59	IVt–D–2.17	
IVtL–0.56	DtL–0.11	
		III– 5.84
IVt–6.99	D–9.64	c–III– 6.68
	D–C– 1.10	CtL– 0.03
I–2.81	Ct– 0.33	
A–I–6.04		C–12.55
AtL–0.21	C–11.07	A–C– 0.11
	xxxxxxxxxxxx	At– 0.02
A–9.06	II– 2.81	
	A–II– 9.90	A–12.68
	AtL– 0.21	
	A–12.92	
	A–S– 1.07	
	S–13.99	
	STRAINER– 1.00 (EST)	
	Total–14.99 lb/sq. in. (Max.)	

Note: Losses are computed on the basis of maximum cooling water flowing simultaneously in all the coolers. Loss in branch connection principally due to turbulence in main.

TABLE IV.—FRICTION LOSSES*

1	2	3	4	5	6	7	8	9
Pipe Size	90° Elbow	45° Elbow	Run Tee	Branch of Tee	Open Gate Valve	90° Bend	45° Bend	Abrupt Changes Cont. in Diam.
3½"	9½'	5'	6'	20'	1'	4'	3'	5"–6" 3'
4"	11'	6'	7'	22'	2'	5'	4'	3½"–6" 3'
5"	14'	9'	9'	28'	3'	7'	5'	12"–10" 5'
6"	16'	11'	11'	34'	3½'	8'	6'	10"–6" 5'
10"	26'	17'	17'	57'	5½'	13'	8'	16"–14" 5'
12"	32'	20'	20'	65'	6½'	16'	12'	14"–12" 6'
14"	36'	23'	24'	80'	8'	18'	13'	14"–6" 7'
16"	42'	28'	27'	90'	9'	21'	16'	4"–6" 4'
								16"–3½" 3'

*Losses are expressed in equivalent lengths of straight pipe.

The arrows in Table III connect branch points. The next loss in the system is always added to the branch with the greatest friction loss. This is repeated until the source, S, is reached. The worst run in the system with respect to friction drop is the run from cooler II to the source. Including the basket strainer, whose loss varies with the amount of sediment collected, the total drop is 14.99 lbs. per sq. in. This permits no safety factor other than that in the formula used.

Table V tabulates the variables in the cost of the flanged job. Costs of pipe and pipe hanging are omitted because these will be essentially the same for a welded job. The number of fittings is derived from the layout drawing, Fig. 2. The cost of fittings is net after discount for resale is figured. Labor units are those of a local refining company which has turned to welding exclusively for pipe joints and fittings.

TABLE V.—ESTIMATED COST OF FLANGED JOB
All flanged fittings are standard 125 lb. cast iron fittings faced & drilled at factory.

	Number Required	Cost of Fittings Each	Cost of Fittings	Labor Man Hrs. Each	Labor Man Hrs. Total
90° Elbows					
3½"	9	$ 3.23	$ 29.07	1½	13½
4"	4	3.63	14.52	1½	6
5"	11	4.78	52.58	1½	16½
6"	3	5.87	17.61	1½	4½
12"	2	20.55	41.10	8	16
14"	2	29.90	59.80	10	20
16"	4	39.27	157.08	10	40
45° Elbows					
3½"	2	3.53	7.06	1½	3
5"	3	5.22	15.66	1½	4½
6"	1	6.38	6.38	1½	1½
12"	4	21.45	85.80	8	32
14"	4	29.90	119.60	10	40
Tees					
3½"	2	4.68	9.36	2	4
6"	2	9.64	19.28	2	4
6" Red.	4	8.54	34.16	2	8
10" Red.	2	23.50	47.00	10	20
12" Red.	2	33.52	67.04	10	20
14" Red.	4	49.20	196.80	12	48
16" Red.	2	65.10	130.20	12	24
Flanges					
3½"	30	1.04	31.20	Used with Fittings	
4"	12	1.19	14.28		
5"	36	1.35	48.60		
6"	30	1.65	49.50		
6" Red.	19	2.51	47.69		
10" Red.	4	3.63	14.52		
12"	16	5.05	80.80		
14"	20	6.73	94.60		
16"	8	10.10	80.80		
TOTAL			$1532.09		325½

(Table continued on Page 878)

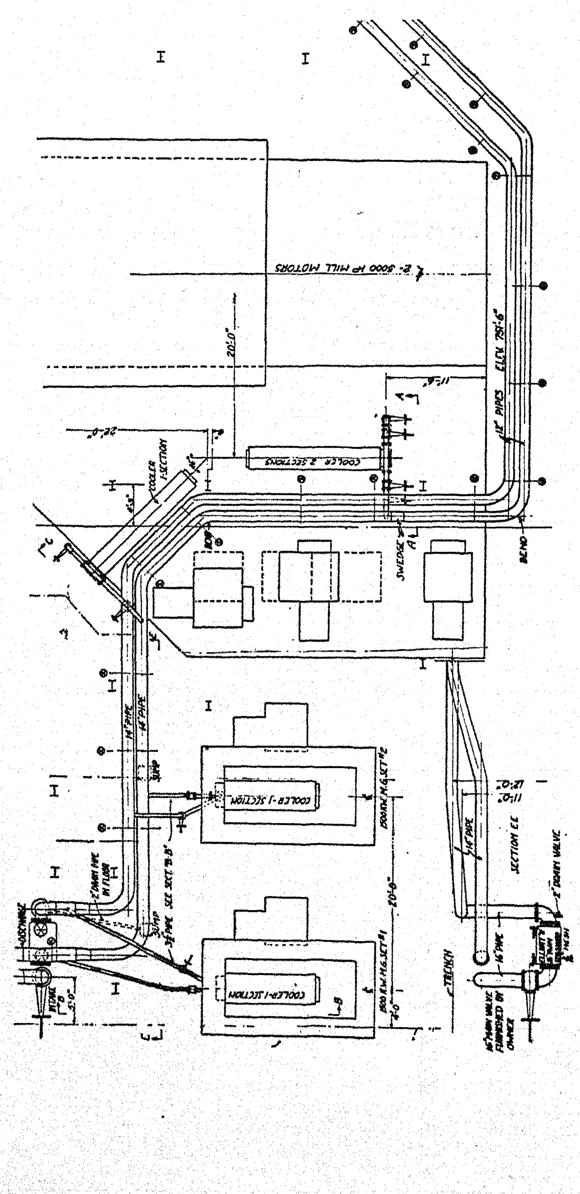


Fig. 4. Final piping layout. This connects at "I-I" with sketch on page 877b.

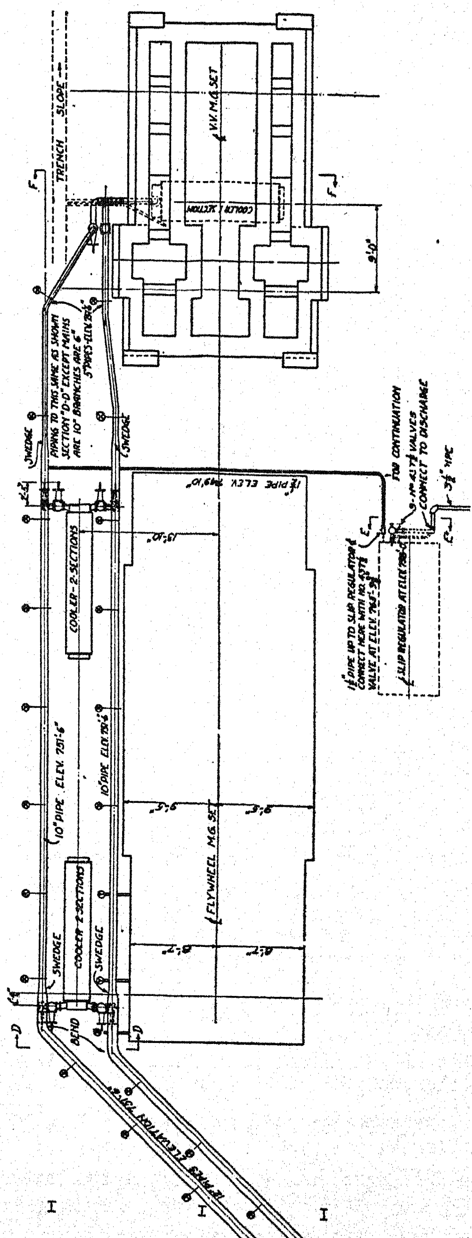


Fig. 4. Final piping layout. This connects at "I-I" with sketch on page 877a.

TABLE V.—(CONTINUED)

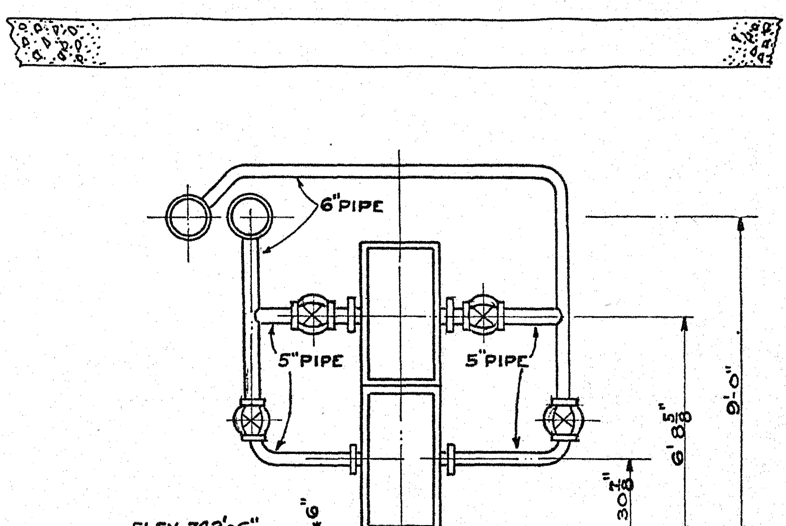
	Number	Cost Each	Total	Hours Labor Each	Hours Total Labor
Unions					
3½″ Cost includes bolts, nuts, and gasket	4	$ 1.17	$ 4.68	1	4
10″	4	7.58	30.32	6	24
12″	6	10.56	63.36	6	36
14″ (2 companion flanges)	2	13.82	27.64	8	16
16″ (2 companion flanges)	2	20.42	40.84	8	16
Valves—Outside Screw and Yoke					
3½″	4	19.90	79.60	1½	6
4″	2	24.30	48.60	1½	3
5″	10	33.10	331.00	2	20
6″	4	37.80	151.20	2	8
16″	2	Supplied by Owner		12	20
Gasket, 1/16″ Cloth Inserted Rubber					
3½″	36	0.09	3.24		
4″	14	0.11	1.54		
5″	58	0.12	6.96		
6″	52	0.15	7.80		
10″	4	0.28	1.12		
12″	16	0.38	6.08		
14″	14	0.46	6.44		
16″	12	0.54	6.48		
Am. Std. Bolts—Sq. Hd. with Hex. Hd. Nuts					
5/8″x2½″ (3½″ pipe)	8x36=288	3.84/C	11.06		
5/8″x2¾″ (4″ pipe)	8x14=112	3.84/C	4.30		
¾″x2¾″ (5″ pipe)	8x58=464	5.16/C	23.94		
¾″x3″ (6″ pipe)	8x52=416	3.16/C	21.47		
7/8″x3½″ (10″ & 12″ pipe)	12x20=240	8.12/C	19.49		
1″x4″ (14″ pipe)	12x14=172	11.60/C	19.95		
1″x4″ (16″ pipe)	16x12=192	11.60/C	22.27		
TOTAL			$2,473.47		478½

SUMMARY:

Material	$2,473.47
Labor 482.5 hrs. at $1.50/hr.	723.75
TOTAL COST, FLANGED	$3,197.22

Welded and Flanged Job.—The high cost of fittings and the large quantity of labor on the flanged job invites a comparison with welding. The valves remained flanged because of the owner's preference. Each cooler is equipped with 6″ flanged nozzles so those nozzles vertically mounted inside concrete foundation walls were also fitted with flanged elbows. All other cast iron fittings such as tees, couplings, and the

rest of the elbows, were eliminated in the welded and flanged layout, shown in Fig. 3. Tees are made by burning a hole in the main and butt-welding the branch pipe in place. Elbows are replaced by bends in the pipe. The pipe is shop fabricated and need only be welded in place in the field. The longer runs of pipe require several lengths of pipe butt-welded together. Reducing fittings are eliminated by swaging the larger pipe and butt-welding to the small pipe. Many abrupt changes are thereby eliminated. Furthermore, the bends may be made with such curvature as to have minimum loss and maximum strength. Five was chosen as the ratio of bend radius to pipe diameter since this is standard practice. The loss in such a 90° bend is less than ½ the loss in a cast iron fitting (see Table IV for reference).



SECTION "A-A"

Fig. 5. Typical cross section of cooler connections.

Table VI tabulates the calculation of pressure loss in the welded and flanged job in the manner described previously. Equivalent lengths are taken from Table IV. A search by the Engineering Societies Library in New York failed to reveal any experimental measurements on losses in welded branch connections. The lack of information suggests that the loss is no worse than in a flanged tee. The loss in the run of a flanged tee is eliminated, however. Swaged changes in pipe size were not considered worthy of calculation since the change is gradual and even the loss of abrupt changes in size is very small.

TABLE VI—CALCULATION OF PRESSURE DROP—WELDED AND FLANGED JOB

Run	Pipe Size	Number 90° Ells	Equivalent Length of Ells	Number 45° Ells	Equivalent Length of 45° Ells	Number of Tees	Equivalent Length of Tees	Number of Valves	Equivalent Length of Valves	Number of Reductions & Expansions	Equivalent Length of Red. & Exp.	Actual Length Feet	Total Equiv. Length Feet	Gallons per Minute	Pressure Drop Lb/Sq. In.	Velocity Ft/Sec.
F-X	5"	2C, 3B	49	1B	5			2	6	2, 5-6; 2, 10-5	16	90	166	410	2.5	6.7
IX-VIIIt	6"	2B	16					2	7			12	35	487	0.32	5.5
VIII-VIIIt	6"					2L	68	2	7			4	79	487	0.71	5.5
VIIIt-F	6"									2, 10-6	10	5	15	975	0.48	11.0
FtL	10"					2L	90					0	90	975	0.22	
EF	10"											100	100	1425	0.49	5.8
VII-VIt	5"	2B	14					2	6	2, 5-6	6	12	38	487	0.85	7.9
VI-VIt	5"							2	6	4, 5-6	12	4	22	487	0.48	7.9
VItL	6"					2L	56					0	56	487	0.51	
VItE	6"									2, 10-6	10	5	15	975	0.48	11.0
EtL	10"					2L	90					0	90	975	0.22	
DE	12"	2B	32	4B	48							208	288	2400	1.48	6.8
V-IVt	5"	2B	14					2	6	2, 5-6	6	12	38	517	0.94	8.4
IV-IVt	5"							2	6	4, 5-6	12	6	24	517	0.59	8.4
IVtL	6"					2L	56					0	56	517	0.56	
IVt-D	6"	2B	16							2, 14-6	14	15	45	1034	1.6	11.7
DtL	14"					2L	156					0	156	1034	0.11	
D-C	14"			4B	52							66	118	3434	0.82	8.0
CtL	14"					2L	156					0	156	516	0.03	
C-III	4"	4B	22					2	4	2, 4-6	10	22	58	516	4.3	13.1
B-C	14"											42	42	3950	0.03	9.2
BtL	14"					2L	156					0	156	300	0.01	
B-II	3½"	2C, 3B	35					2	4	2, 3½-6; 2, 14-3½	18	23	80	300	4.2	10.0
AB	14"	2B	37									34	71	4250	0.64	9.9
A-I	3½"	2C, 3B	35					2	4	2, 3½-6; 2, 16-3½	19	42	100	300	5.34	10.0
AtL	14"					2L	156					0	156	300	0.01	
AS	16"	2C, 2W	126					2	18			20	164	4550	0.85	7.2

Note: t = Tee at that point or directly opposite point.
L = Run through branch of Tee. C = Cast-iron fitting; B = bend; W = welding ell

TABLE VII.—SUMMARY OF PRESSURE DROPS WELDED AND FLANGED JOB

Run Loss	Run Loss	Run Loss
X-3.03	IX-5.41	VIII-5.41
F-X-2.50	IX-VIIIt-0.32	VIII-VIIIt-0.71
——	——	——
F-5.53	VIII-t-5.73	VIIIt-6.12
		VIIIt-F-0.48
VI-5.41	VII-5.41	FtL-0.22
VI-VIt-0.48	VII-VIt-0.85	——
VItL-0.51	——	F-6.82
——	VIt-6.26	EF-0.49
VIt-6.40		——
VIt-E-0.48	V-5.84	E-7.31
EtL-0.22	V-VIt-0.94	DE-1.48
——	——	——
E-7.10	IVt-6.78	D-8.78
xxxxxxxxxxxx		D-C-0.82
IV-5.84	III- 5.84	——
IV-IVt-0.59	C-III- 4.30	C-9.60
IVtL-0.56	CtL- 0.03	
——	C-10.17	II-2.81
IVt-6.99	B-C- 0.03	B-II-4.20
IVt-D-1.6	——	BtL-0.01
DtL-0.11	B-10.20	——
——	A-B- 0.64	B-7.02
D-8.70	——	
	A-10.84	
I-2.81	A-S- 0.85	
A-I-5.34	——	
AtL-0.01	S-11.69	
——	STRAINER- 1.00 (EST)	
A-8.16	——	
	Total-12.69 lb/sq. in.	

Note: Loss in branch connection principally due to turbulence in main. Losses are computed on the basis of maximum cooling water flowing simultaneously in all coolers. Pipe sizes same as Table III.

Table VII summarizes the pressure drops in the welded and flanged job in the manner described for Table III. A comparison of the two brings out sharply the reduction in friction loss by the introduction of welding. The maximum pressure drop is 12.69 lbs. per sq. in. compared to 14.99 lbs. per sq. in. for the flanged job, despite the use of the same size pipe. This is a reduction in friction loss of 15% which means that 15% less power is required by the pumps to circulate the same water in the same pipes now welded instead of flanged. The actual reduction in pipe friction drop is greater than this since the above figures include the drops through the coolers themselves and the large strainer. The reduction in friction loss will justify the use of smaller sizes of pipe in some runs. However, this system is designed for hard service in a steel mill, so the saving is utilized to make a better piping system, able to stand overloading and abuse.

Table VIII gives the estimated cost for arc welded and flanged construction. Labor units for bends and swedges are from the same refining company source used in Table V. Welding time and welding rod required are derived from page 870, "Procedure Handbook of Arc Welding Design and Practice," 1938. The total variable cost for the

welded and flanged job is $1,682.35 as compared to $3,197.22 for the flanged job. A saving of 46.8% is observed in the variable cost factors. Furthermore, labor hours are reduced from 482.5 hours to 405.75 hours, a reduction of 15.9%.

If the welded job were only as good as the flanged, the welded would be chosen on the basis of direct cost and indirect cost such as reduction of friction loss. But the welded job has also other advantages over the

TABLE VIII.—ESTIMATED COST—ARC WELDED AND FLANGED
Non-welding operations

	Number Required		Man Hrs. Each	Total Man Hrs.	Cost Each	Total Cost
90° Bends						
3½"	4		1½	6		
4"	4		2	8		
5"	10		2½	25		
6"	6		3	18		
12"	2		10	20		
14"	2		15	30		
45° Bends						
12"	4		7	28		
14"	4		14	56		
Valves O.S.& Y.						
3½"	4		1½	6	$19.90	$ 79.60
4"	2		1½	3	24.30	48.60
5"	10		2	20	33.10	331.00
6"	4		2	8	37.80	151.20
16"	2		10	20	Supplied	by Owner
Flanged ells						
6"	6		1½	9	5.87	35.22
Gaskets						
3½"	8				0.09	0.72
4"	4				0.11	0.44
5"	24				0.12	2.88
6"	40				0.15	6.00
16"	6				0.54	3.24
Flanges						
3½"	8				1.04	8.32
4"	4				1.19	4.76
5"	20				1.35	27.00
6"	12				1.65	19.80
6" red	16				2.51	40.16
16"	6				10.10	60.60
Bolts						
⅝"x2½" (3½" fitting)	8x 8	64			3.84/C	24.50
⅝"x2¾" (4" fitting)	8x 4	32			3.84/C	12.25
¾"x2¾" (5" fitting)	8x24	192			5.16/C	9.91
¾"x3" (6" fitting)	8x40	320			5.16/C	11.51
1"x4" (16" fitting)	16x 6	96			11.60/C	11.14
TOTAL				257		$888.85

(Table continued on Page 883)

ARC WELDING OPERATIONS (Table VIII continued)

Butt Welds	No.	Welding Time Minutes Per Joint	Total Welding Time Minutes	Welding Rod Per Joint	Total Welding Rod Lbs.	Bevelling Two Pipes Hrs. Each	Bevelling Two Pipes Hrs. Total
3½″ (taken as 3″)	8	7.0	56	0.44	3.52	¼	2
4″	2	9.0	18	0.64	1.28	½	1
5″	16	11.3	181	0.81	12.96	½	8
6″	8	13.5	108	0.96	7.68	¾	6
10″	6	22.0	132	1.65	9.90	1	6
12″	12	26.5	318	2.00	24.00	1½	18
14″	8	31.3	251	2.30	18.40	2	16
*16″	8	36	288	2.65	21.20	2	16
TOTALS			1352		98.94		73

MISCELLANEOUS

	No.	Labor Including Layout	Total Labor Hours	Cost Each	Total Cost
Burning holes in pipe for tees—					
3½″ branch—16″ main	4	½	2		
4″ branch—14″ main	2	½	1		
5″ branch— 6″ main	4	1	4		
6″ branch— 6″ main	2	1	2		
6″ branch—14″ main	2	1	2		
6″ branch—12″ main	2	1	2		
6″ branch—10″ main	2	1	2		
1½″ branch—10″ main	1	¼	¼		
16″ 90° welding ells	4	Included Under Welding		$42.47	$169.88
Swages					
6″ to 5″	4	1	4		
12″ to 10″	2	4	8		
14″ to 12″	2	5	10		
16″ to 14″	2	5	10		
10″ to 5″	2	3	6		
TOTALS			53¼		$169.88

SUMMARY:	Non welding material	$888.85
	Welding ells	169.88
	98.94 lb. welding job at $ .09 per lb.	8.91
	**40 cu. ft. oxygen at $3.50 per 100 cu. ft.	1.40
	**12 cu. ft. acetylene at $1.40 per 100 cu. ft.	.18
	1352 min. of electric welding machine operation at $ .05 per KWH	4.50
	405¾ hrs. labor at $1.50 per hr.	608.63
	TOTAL COST WELDED AND FLANGED	$1,682.35

*Estimated by extending plotted curve to 16″

**Gas required for burning holes in mains for branch piping.

flanged that reflect in a better job although these are difficult to evaluate in dollars. Most important is the greater strength of the welded joint. The table below gives the reduction in wall thickness for the required standard steel pipe when threaded for a flanged joint.

Pipe Size	Wall Thickness Inches	Depth of Am. Std. Pipe Thread	Reduction of Wall Thickness
3½"	0.226	0.1"	44.2%
4"	0.237	0.1"	42.2%
5"	0.258	0.1"	38.7%
6"	0.280	0.1"	35.7%
10"	0.307	0.1"	32.6%
12"	0.330	0.1"	30.3%

A flanged joint is therefore weaker than the pipe it joins. But a welded joint is stronger than the pipe, because the weld metal deposited from a specially prepared welding rod is fine grained and homogeneous, permitting excellent fusion with the larger-grained steel pipe.

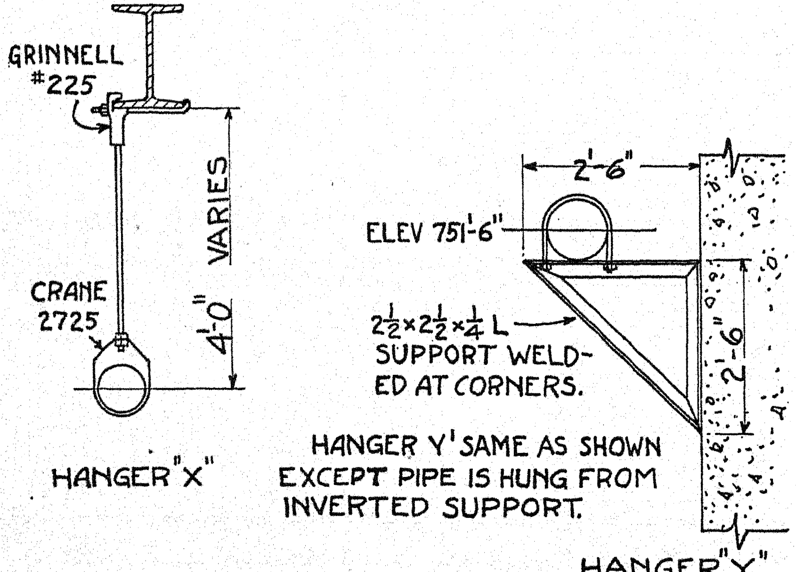


Fig. 6. Pipe supports.

A comparison of Figs. 2 and 3 shows the simplicity introduced by welding. This simplicity is reflected in several ways. Welding eliminates 124 gasketed joints, thereby reducing maintenance and possibility of system shutdown. The concentration of expensive electrical equipment demands cleanliness and freedom from leaks. Elimination of large, bulky, flanges increases head room in the basement and decreases the difficulty of enclosing each cooling group in an air chamber, which is made of ¼" steel plate.

An examination of Fig. 4 shows how space requirements favor the welded job. Pipe clearances are less and the job is neater. If, at a later date the mill management applies anti-sweat covering to the pipes, very few flanges are present to interfere.

Furthermore, the general elimination of cast elbows simplifies the run from the coolers at the main drives to those at the flywheel set. Bends may be made at any convenient angle which need not be available in standard castings. Note in section EE of Fig. 4 how easily a drain is added to the bottom elbow at the strainer. No special fittings are required here or elsewhere. The lack of many large, bulky fittings reduces cartage and labor in placing these fittings in the motor room basement of a very large mill. Fig. 5 shows a typical cross section of the cooler connections. Pipe supports are shown in Fig. 6. Note the use of simple welded brackets made right on the job.

Summary.—The arc welded piping system offers:

1. 15% reduction in friction loss.
2. 46.8% reduction in cost of labor and material for joints and fittings.
3. 15.9% reduction in labor hours.
4. 124 fewer gasketed joints to maintain.
5. Stronger joints.
6. Neater, simpler, job.
7. Flexibility of design—elimination of cast fittings.
8. Less cartage and miscellaneous labor.
9. More head room in basement.

These advantages have led to the general adoption of arc welding for industrial piping.

Finis.—The contract for the erection of this piping system was let as an arc welded job with flanged valves.

Chapter VIII—Design of an Arc Welded Penstock of Nickel-Clad Steel

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The subject matter of this paper is an actual routine design of a penstock for an existing hydro-electric power plant, taking advantage of all modern practice in the electric welding and the selection of new materials.

The economic comparison of the designs and other costs will be made by setting up respective costs: (1) of an electric welded pipe as actually built; and, (2), a pipe fabricated of nickel-clad steel also by the electric welding method.

The comparison will be made as to first costs, interest on capital investment over life period of fifty years, power loss due to different smoothnesses of inner surfaces, maintenance costs such as repainting, reliability of service and its reflection towards the cost of other features of the installation. The penstock covered by this design is a redesign of an electric welded penstock fabricated of the usual plate steel in the conventional manner. The project for which this design is made consists of a plant of three units, two of which were installed in 1920 of the usual riveted type, the third unit being installed in 1932, using the newly developed electric welding methods, but using ordinary steel plate.

The nickel-clad steel penstock designed and described in this paper is a routine design and study of methods and costs such as are made before determining the feasibility and economy of accepting a new method of construction. Although the identical project will not be used for future installation, it was used to arrive at a conclusion as to other designs of new projects under contemplation.

Cost figures, construction, maintenance and operation are included for all types of penstocks; namely, riveted, welded steel and nickel clad steel.

The purpose of this paper is to determine the various economies and benefits of the nickel clad steel penstocks over one of the conventional welded steel. Attention is directed to a comparison of the relative merits of the two classes of welded steel construction, the riveted design being included only to serve as a starting point to indicate the trend of better hydraulic designs made possible by the introduction of welding, and that although great advances were made in changing from riveting to welding, a greater advance in the direction of economy and reliability is shown by changing from welded steel to nickel clad welded steel.

It has been the vision of hydraulic engineers for many years to be able to build power penstocks with inner surfaces of some non-corrosive material other than paint or hot enamel which would give the continuous

low friction losses and lack of maintenance desired, and it has only been with the advent of the recent developments in processes of welding that it has been made possible to use nickel for the inner surfaces of such pipes.

It is, therefore, the aim of this paper to prove that penstocks of welded nickel clad steel are the most economical to construct and maintain.

Source of Information.—The source of all information used in this study is only reliable data which are being used at present for design and cost analysis purposes.

All steel costs are actual quotations from reliable firms regularly employed in fabricating and producing such materials. All erection costs are actual costs as have been obtained from other jobs of erecting and welding.

Stresses in the plate from which the various diameters of the pipes were obtained are the same for both the riveted and welded steel with the exception of the joint efficiencies as used in their original designs, while the stress in the nickel clad steel pipe is that of modern practice due to the higher strength of the plate employed. Friction losses are determined from the usual coefficients used in calculating the losses in new, old and repainted penstocks of the three grades of inner surfaces.

The value of a kilowatt hour as used in evaluating the friction loss is the value obtained from past years' operating data by taking the total gross income from all sold power, deducting all operating and maintenance costs, overhead, interest on all outstanding debts, retirements of debts, capital set aside for depreciation and all other expenses, and using this remainder or annual surplus which is available for betterments, extensions, increasing of generating capacities or reduction of rates, and reducing it to a mills per kw-hr. rate based on the total kw-hrs. sold over a like period of time. This value obtained is somewhat higher than that used, but as this study is extended into the future over a long period of time, the minimum value of the kw-hr. that can possibly be used today was taken as a start, reducing it each year for the period under consideration as increased economies indicate the trend to be.

General Information.—In making the comparative studies, a fifty year period was chosen as one which would be of sufficient duration to give a true picture of the relative value of the two penstocks. At the close of such a time the regular forty-year amortization period of the lines would have elapsed and the normal length of life for a pipe line have been reached. During this time in order to preserve the steel, it would have been necessary to repaint each of the lines on the outside with one coat of paint at the end of each seven years. This has been proven to be the economical time to repaint to minimize the heavy repainting costs incurred if longer periods are taken. The plain steel pipes will need to be cleaned and re-enameled on the inside at the end of thirteen-year periods. This also is the limit of time that the best of enamels prove effective, as by this time serious corrosion has already commenced to appear.

In arriving at the details of the nickel clad steel, advantage is taken

of the greatly decreased friction loss which makes it possible to use smaller diameters of pipe. These smaller diameters again reflect as savings, as a thinner wall section can be used at the same static head. In all previous designs using the steels available, the working stresses were low, as the elastic limit was about 32,000 lbs. per sq. in. Tests were made of nickel clad steel welds and base plates, and the average of many tests was 70,000 lbs. per sq. in. ultimate strength and 45,000 lbs. per sq. in. yield point with no variation in either direction of more than 1.2%. In no case did a test bar break in the weld or within 1" of the weld.

Although the penstocks as laid out in their original locations are of various lengths due to turning corners, one length was selected for all designs in order that the costs might be kept upon the same basis. No fixtures such as manholes, nipples for air or vacuum valves, pass holes, expansion joints, anchors, piers or other fixtures which are alike in all cases, were included in this analysis, as they add to the total cost equal amounts. The only items other than that of the pipe itself which were included are the penstock saddles and the shutoff valve or butterfly valve at the upper end. The saddles were included because in previous installations cast iron has been used, these castings requiring the additional expense of patterns. The saddles for the nickel clad steel line are made of structural steel rolled to the curvature of the pipe with bar lugs welded in place. The butterfly valve was included as an item because its size and cost is affected by the diameter of the line which is considerably smaller for the nickel clad steel.

General Estimating Data.—The following general data were used in the design of the nickel clad steel penstock.

18.5c per lb. for fabricated penstock F.O.B. local shop.
2% overhead added to all heavy fabricated materials shipped direct to field.
10% overhead added to all materials sent through general warehouse.
34% overhead added to all labor charges.
70,000 lbs./sq. in. ultimate strength of nickel clad steel.
45,000 lbs./sq. in. yield point of nickel clad steel.
18,000 lbs./sq. in. working fiber stress in net section.
.68c per lb. for transportation on materials from local shops or warehouse to site.
3½% value of money for year.
5.80 mills value of a Kw-hr. for the first year.
3.35 mills value of a Kw-hr. for the last year of the study, the value of the Kw-hr. being graded downward in increments of .05 mills per year.

Design of Nickel Clad Steel Penstock.—The design of the nickel clad steel penstock is a comparative redesign of the existing third unit penstock which was installed in 1932 of welded construction of the usual arc welding quality steel plates.

In determining upon the diameter of the new penstock, advantage was taken of the fact that with a nickel clad surface higher velocities of water for the same quantity of flow can be used. This decreased

inside diameter results in a lighter penstock as the thickness of plate can be reduced for the same head. It is, therefore, possible to arrive at a number of pipe sizes and weights, depending upon which is considered the more valuable, low first cost and higher friction loss or a greater first loss and lower friction loss. After making a series of test set-ups of tentative diameters, the first costs and their operating costs were obtained.

From these studies it was determined that the inside diameters ranging from 78″ down to 68″ should be used in place of 84″ to 72″. Although these diameters do not give the lowest possible first cost figures, the power saving over the period of time used affects this from a financial standpoint and the plant possesses a larger generating capacity which is valuable for peaking purposes.

In calculating the wall thickness necessary for any particular diameter, the following formula was used:

$$.433\ hD = 2t \times 1 \times 18{,}000$$

where, .433 = ratio of head to lbs./sq. in.
h = head of water at the point in reference, in feet.
D = inside diameter of pipe in inches.
2 = two areas of plate in tension in any section.
t = thickness of the shell in inches.
1 = 1″ of pipe used as a band.
18,000 = working stress in tension used in the net section of the tube.

This formula reduces to:

$$h = \frac{t \times 2 \times 1 \times 18{,}000}{.433D} = 83{,}141 \quad \frac{t}{D}$$

and gives the greatest head (h) at which a pipe section of (t) inches thickness and (D) diameter can be installed under the maximum allowable working stress of 18,000 lbs./sq. in. in tension.

From this a tabulation of calculations was made, all hydraulic heads being taken from the maximum high water elevation in the surge tank at 2055 feet above sea level

D	t	h	Elevation	L	lbs./ft.	Wt. Lbs.
78″	$3/8$″	399.0′	1656.0′	1,162.25′	330	377,650
74″	$3/8$″	421.0′	1634.0′	32.88′	310	11,880
70″	$3/8$″	445.0′	1610.0′	35.89′	296	10,440
70″	$7/16$″	515.5′	1539.5′	121.21′	346	41,140
68″	$7/16$″	534.0′	1521.0′	22.87′	336	7,590
					Total Weight, Lbs.	448,700

From past experience of shop welding and making numerous tests of actual welds, the usual procedure of using butt welded longitudinal joints was adhered to. The welds were to be made by "V"-notching the plates, the opening of the "V" being on the mild steel side. The pipe is to be lightly spot tacked on the steel side and a single pass of pure nickel rod laid along the abutting clad side. This pass is to be made by hand or by an approved machine, depending upon the fabricator. The mild steel tacks which were used to hold the cylinder in shape during

nickel welding are then to be chipped out and the "V" filled on the steel side by some approved automatic machine weld. Tube sections are then to be shop butt welded in like manner into shipping lengths of from 30 to 40 feet depending upon the distance between elbows.

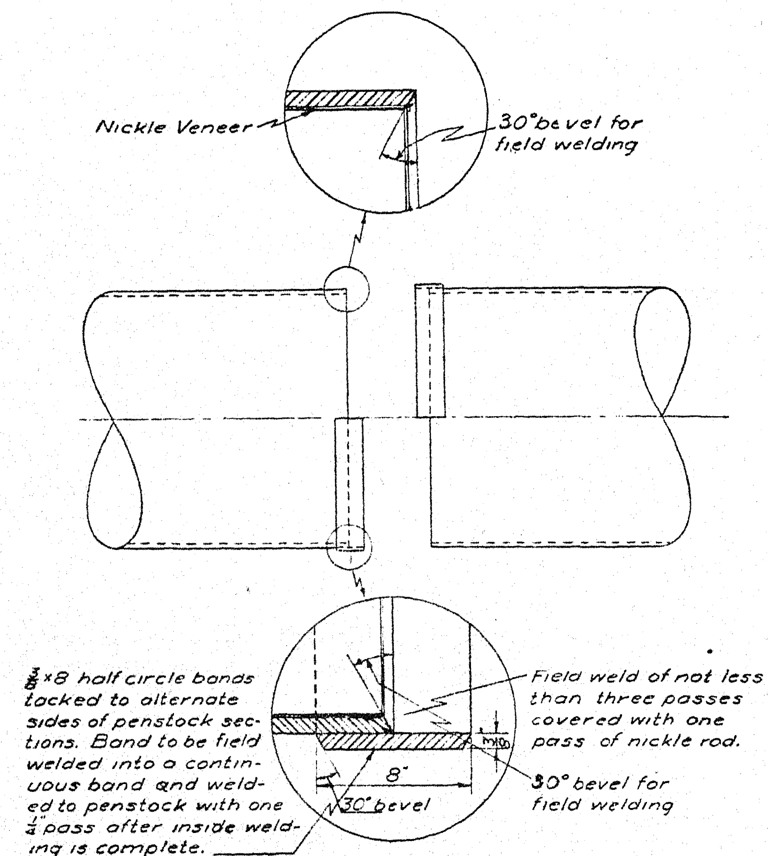
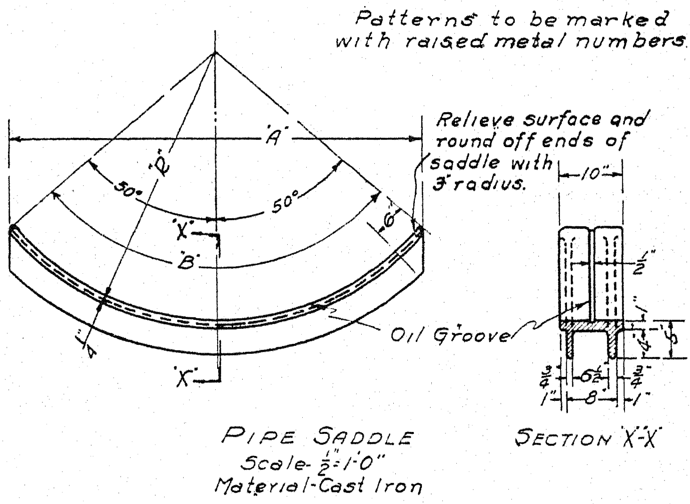


Fig. 1. Half circle band lightly tackwelded to tubes.

Each end of each shipping section is to be provided with a half circle band lightly tacked to the tubes as shown in Fig. 1. The field welds joining these plates to the shell are not to be considered as stress bearing, and are to be made lightly of a single pass after the butt weld on the inside has been completed. The straps are only to be used for ease of erection and alignment and not as longitudinal strengthening.

All field welding is to be done with the pipe erected up hill from anchors placed at the ends of all major long runs of pipe. Expansion joints are placed just below each anchor and are the final connection in each run taking up all gain or loss in penstock erection length.

The expansion joints were omitted in making the cost analysis from both types of penstocks as their slight difference in cost would not affect the economics of the line. In the past, all expansion joints have been made of cast bronze or stainless steel sleeves.



PART №	R	A	B	PATT. №	№ Req'd
1	44"	5-7 9/16	6'-4 3/4	754	30
2	42"	5'-4 3/8	6-1 5/16	737	2
3	40"	5'-1 15/16	5'-9 7/8"	738	4
4	38 1/2"	4'-11"	5'-7 1/4"	739	5

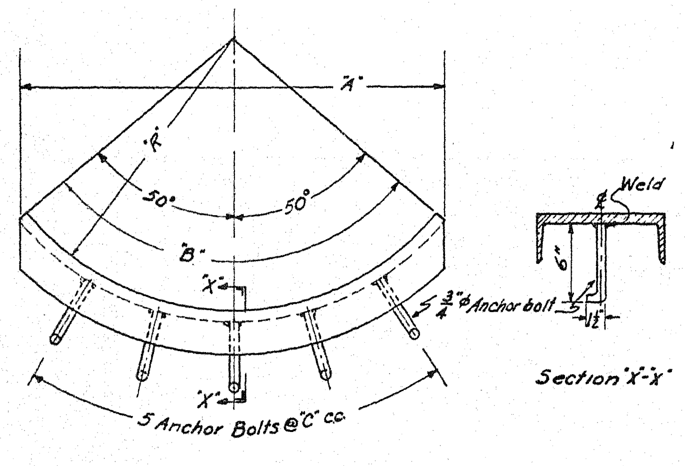
Fig. 2. Cast iron saddle.

Although the costs of the saddles do not affect the total cost to any great extent, they were included as all saddles in the past have been made of cast iron as shown in Fig. 2. Those shown in Fig. 3 are to be used. These newer saddles are to be rolled of structural steel with welded steel anchor lugs.

Fabrication and Construction of the Nickel Clad Steel Penstock.— SHOP WORK. The fabrication of the penstock begins with the purchaser's specifications. The entire specification such as would be submitted to the various fabricators for bid would be too lengthy to incorporate in a paper of the nature of the one under consideration. Therefore, only the salient points will be stated.

The plate as used in the fabrication of the penstock shall be of the thicknesses stated in the specification drawings with the usual rolling tolerances and variations allowed. The thickness of the plate shall be considered the total thickness of the steel plus the nickel, the thickness of the nickel veneer being 10% of the total thickness. The minimum

ultimate strength shall not be less than 68,000 lbs. per sq. inch on the gross thickness and the yield point not less than 42,000 lbs. per square inch. The nickel shall be securely attached to and made a part of the composite plate by one of the approved methods before cutting and rolling into cylinders.



Elevation

PIPE SADDLE								
Part	Material	"R"	"A"	"B"	"C"	Nº Req.	Wt. Each	Remarks
1	18" @ 21.9# Ship C	39 3/8"	5'-0 5/16"	5'-8 11/16"	14"	36	129.7#	Galv
2	do	37 3/8"	4'-9 3/16"	5'-5 [illegible]/16"	13"	2	123.7#	do
3	do	35 3/8"	4'-6 3/16"	5'-1 11/16"	12½"	3	117.6#	do

Fig. 3. Arc welded steel saddle.

All longitudinal shop welding shall be done by an electric shielded arc method. The plates are to be beveled for machine welding on the mild steel side, rolled to exact and true circles of the specified inside diameter. Light spot tacks are to be placed on the steel side, followed by welding a single pass of coated nickel rod on the nickel side thoroughly and completely joining the nickel veneer into a watertight surface. Excess weld metal may be ground off if this interferes with the mild steel machine weld. The above mentioned tacks are then to be chipped out together with any excess nickel which may have penetrated into the beveled area. The longitudinal weld shall then be completed by machine welding. This welding may be made either by the single or multiple pass method upon approval of a responsible representative of the purchaser.

After welding, all tubes are to be checked for straightness and true diameter. Shop length sections are next joined by the same method into shipping lengths of 20 or 30 feet, odd lengths being taken care of at the

elbows. The lengths of all shipping sections are to be determined upon before fabrication starts and must be adhered to in order that anchors and piers may be located in the field. One standard set of test coupons shall be attached to every 100 feet of pipe and welded together with the pipe proper. These coupons are to be tested in accordance with standard practice in tension, bending all weld metal and nick-break. No tension test sample shall fail in the weld. Seams which may be suspected of being defective are to be X-rayed and if found defective, chipped out and rewelded. All shipping sections are to be cold water pressure tested to 150% of the maximum static hydraulic head under which they will operate. All seams and the area adjacent to them are to be thoroughly cleaned of all flux and spatter.

Half circle bands, as shown in Fig. 1, are to be lightly tacked to each end of each shipping length to be used for field erection.

FIELD ERECTION. All field erection shall start from an anchor location and proceed in an uphill direction. As soon as that section of penstock which will be contained within a pier has been accurately and properly aligned in its true location, the concrete anchor is to be poured.

Shipping length sections are then to be added in an uphill direction, the half circle bands being on the lower side of the upper end of the downhill piece, and on the upper side of the lower end of the uphill piece. These cover plates are only to be used for ease of erection and alignment. As a considerable portion of the line is on a steep hillside, it is difficult to hold the pipe in alignment with several sections prepared for circumferential welding.

The two sections are to be joined on the outside by means of light tacks. The inner butt weld is then to be made. This is made of one pass for one-eighth inch of plate thickness of heavily coated steel rod. All flux is to be completely removed and the weld metal peened before proceeding with the next bead. After the groove has been filled to the level of the bottom surface of the nickel coating a single pass of coated nickel rod is to be neatly placed over the steel producing a continuous, smooth, watertight nickel surface.

All pipe sections are to be held in true alignment by means of temporary saddles prior to the completion of the permanent concrete and steel saddles. The last section of each run between anchors is to be the expansion joint. After all interior welding is completed the exterior bands are to be welded to the shell with one light pass.

The steel saddles, shown in Fig. 3, are then drawn up against the penstock in their final location over the concrete piers which have previously been poured short of their ultimate height. Two layers of heavy wool felt asphalt-treated sheet are to be placed between the pipe and the saddle. The upper sheet is to be cemented to the pipe with asphalt and separated from the lower sheet by a film of flaked graphite. The concrete piers are then cast to their full height embedding the steel saddle within them.

PAINTING. Immediately upon arrival in the field, the inner surface of all penstock sections are to be thoroughly sandblasted and primed with a coal tar base cut back primer. The outer surface is to be thoroughly cleaned of all rust, flux, spatter, grease, dirt or loose mill scale and

primed with pure red lead paint of a synthetic resin vehicle. This first coat is to be followed by a second coat of a similar white lead paint. The penstock sections are now ready for completion of the inside surface which is to consist of a hot applied coating of coal tar enamel, not less than .6 pounds per square foot.

Each end of each section shall be left clean of all paint or enamel for a distance of 4″ from any edge to be welded at a later time. After erection is completed all bare surfaces are to be properly primed and enameled or painted. The entire outer surface of the penstock is then to be given a coat of aluminum paint made of a synthetic resin vehicle.

The above mentioned white lead second coat is used under the aluminum during enameling and erection in order to keep down the temperature of the pipe, thus reducing expansion and contraction and the tendency of the hot enamel to soften and sag.

Table I—Welded Nickel Clad Steel Penstock
Summary of Direct Costs

	Cost F.o.b. Shop	Overhead	Transportation	Field Costs plus Overhead Labor	Field Costs plus Overhead Material
Penstock	$83,010	$1,660	$3,051	....	....
Placing Penstock	....	....	....	$1,825	$ 253
Welding	....	....	24	2,590	1,122
Saddles	356	7	35	....	....
Butterfly Valve	4,500	90	145	200	23
Painting Outside	....	....	19	1,679	539
	$87,866	$1,757	$3,274	$6,294	$1,937
Grand Total			$101,128		

Table II—Nickel Clad Steel Penstock
Maintenance Costs

RE-PAINTING (Outside—1 coat each 7 years)		
27,835 sq. ft. @ 1.5¢/sq. ft. labor	=	$450.
34% overhead on labor	=	153.
65 gal. Paint @ $3.15 per gal.	=	204.
10% overhead on Material	=	20.
1,300 lb. @ .68¢/lb. Transportation	=	9.
		$836.
Yearly inspection and touch up		50.

TOTAL MAINTENANCE COSTS		
Repainting outside each 7 years	= 6 x 836 =	$5,016.
Yearly maintenance	= 44 x 50 =	2,200.
TOTAL		$7,216.

Friction Losses.—In order to determine the economy of operation of the nickel clad steel penstock, it is necessary to determine the friction loss in a pipe of such material and compare this loss to that of a pipe of plain welded steel having the conventional hot enameled inner sur-

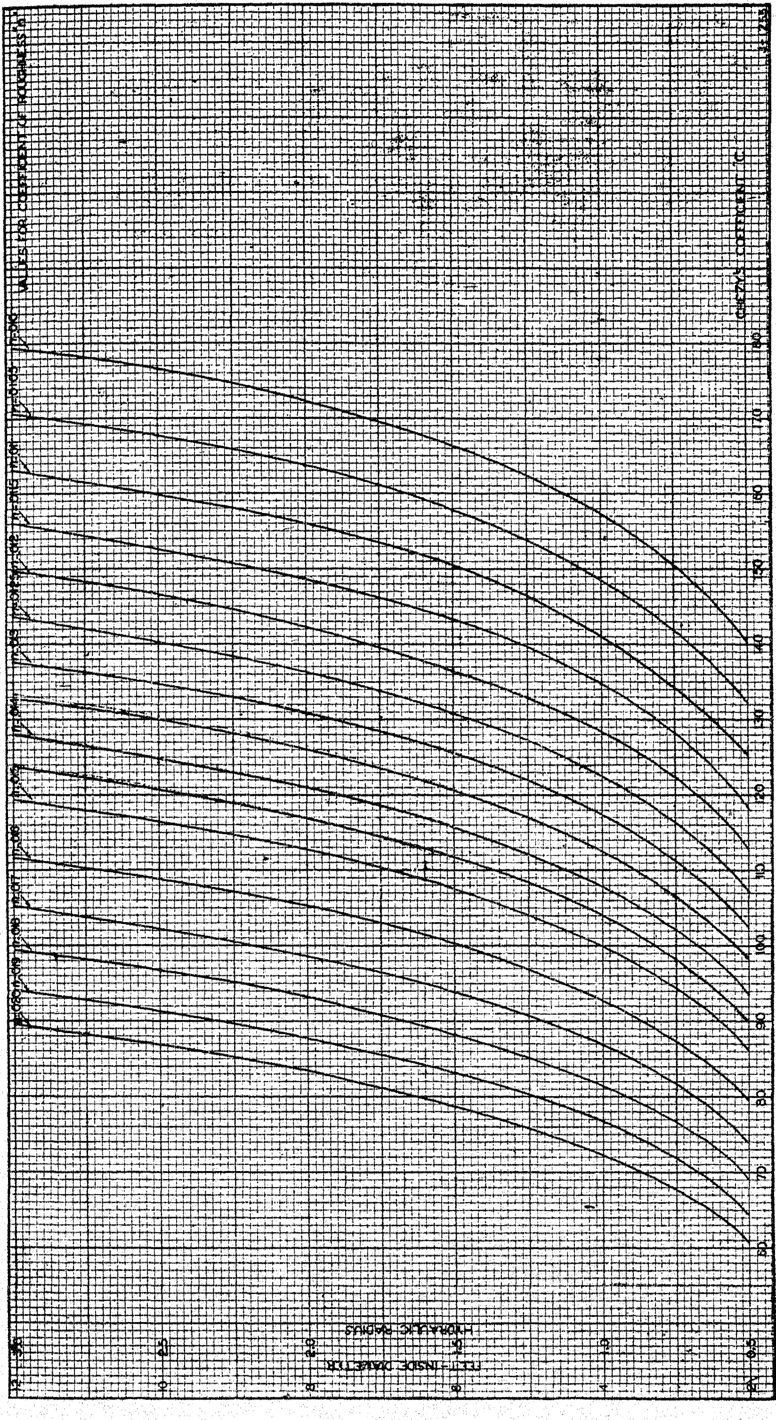


Fig. 4. Values for coefficient of roughness.

face. There is also included the friction loss of an enameled riveted pipe.

The values of "n", the coefficient of roughness, were used as,

n = .0135 for new enameled riveted pipe.
= .0145 for reenameled riveted pipe.
= .0180 for rusted riveted pipe after 13 years service.
= .0120 for new welded pipe.
= .0135 for reenameled welded pipe.
= .0170 for rusted welded pipe after 13 years service.
= .0100 for nickle clad steel pipe.

The values of "C" are obtained from Kutler's formula,

$$C = \frac{41.66 + \dfrac{1.811}{n} + \dfrac{.00281}{S}}{1 + \left(41.66 + \dfrac{.00281}{S}\right)\dfrac{n}{\sqrt{R}}}$$

Where S = the slope of the pipe,
and R = the hydraulic radius.

The values of "C" for various values of "n" and "R" are shown in Fig. 4 for a steep pipe where S is negligible. Values of "C" as used in determining the friction loss were taken from these curves.

The amount of head represented by the friction loss is given by the formula,

$$h = \frac{V^2L}{C^2R}$$

where "V" is the velocity of the water at a given discharge and "L" is the length of the Section of constant diameter under consideration.

For the nickel clad steel penstock the following figures are found at a discharge of 350 second feet, which is the discharge at approximately 80% gate opening.

Diameter	n	C	Q	V	L	h
78	.010	168.0	350	10.55	1,163	2.83
74	.010	167.0	350	12.09	33	.11
70	.010	165.8	350	13.11	157	.64
68	.010	165.2	350	13.36	23	.10

Total head loss = 3.68 feet

In like manner the total head loss for the comparative pipes was found to be,

6.01 feet for new enameled riveted pipe.
7.03 feet for reenameled riveted pipe.
11.29 feet for rusted riveted pipe.
4.54 feet for new enameled welded steel pipe.
5.77 feet for reenameled welded steel pipe.
9.62 feet for rusted welded steel pipe.

These values have been plotted in Fig. 5 in order to obtain intermediate points.

As the static head difference of the elevations of the two ends of the penstock is 470.8 feet, the losses of the various types of pipe are,

A constant loss of 79% for the nickel pipe,
a variable loss of 1.28% to 2.39% for the riveted pipe, and
a variable loss of .96% to 2.04% for the welded pipe.

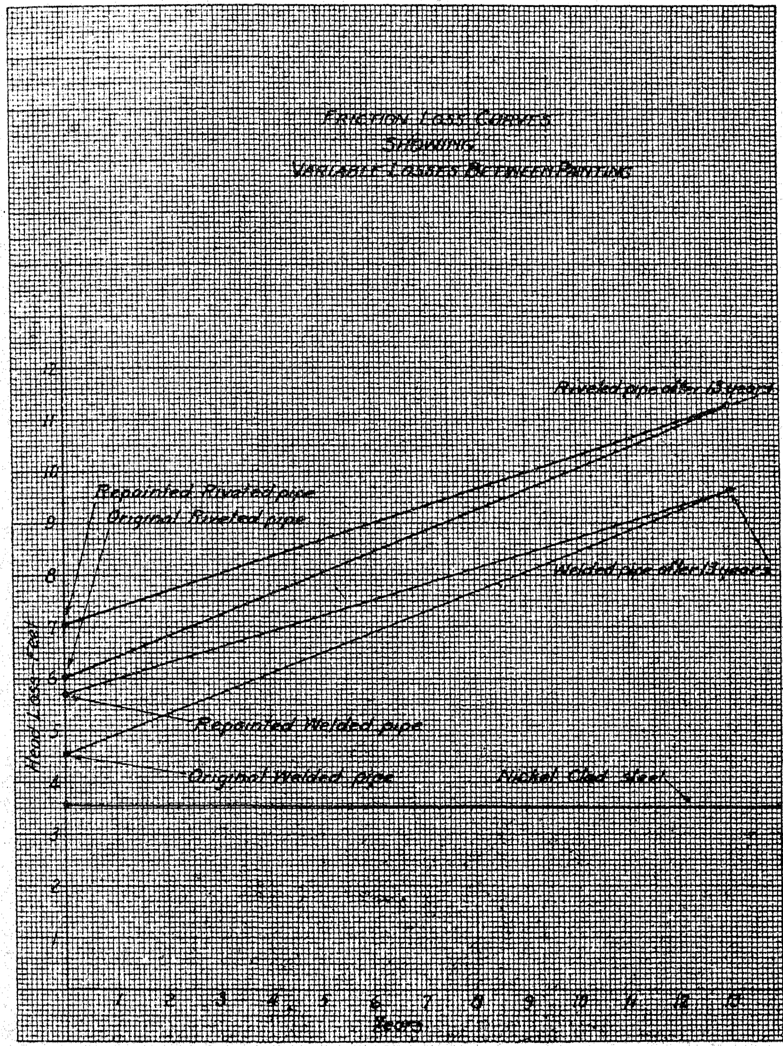


Fig. 5. Friction loss curves showing variable losses between paintings.

At the peak capacity of the turbine which is 420 s.f., the losses of the two lines are 13.85 and 5.32 feet, or a gain of 8.53 feet in favor of the nickel clad steel line. This at an overall efficiency of the plant of 81% represents an excess generating capacity of 183 kw.

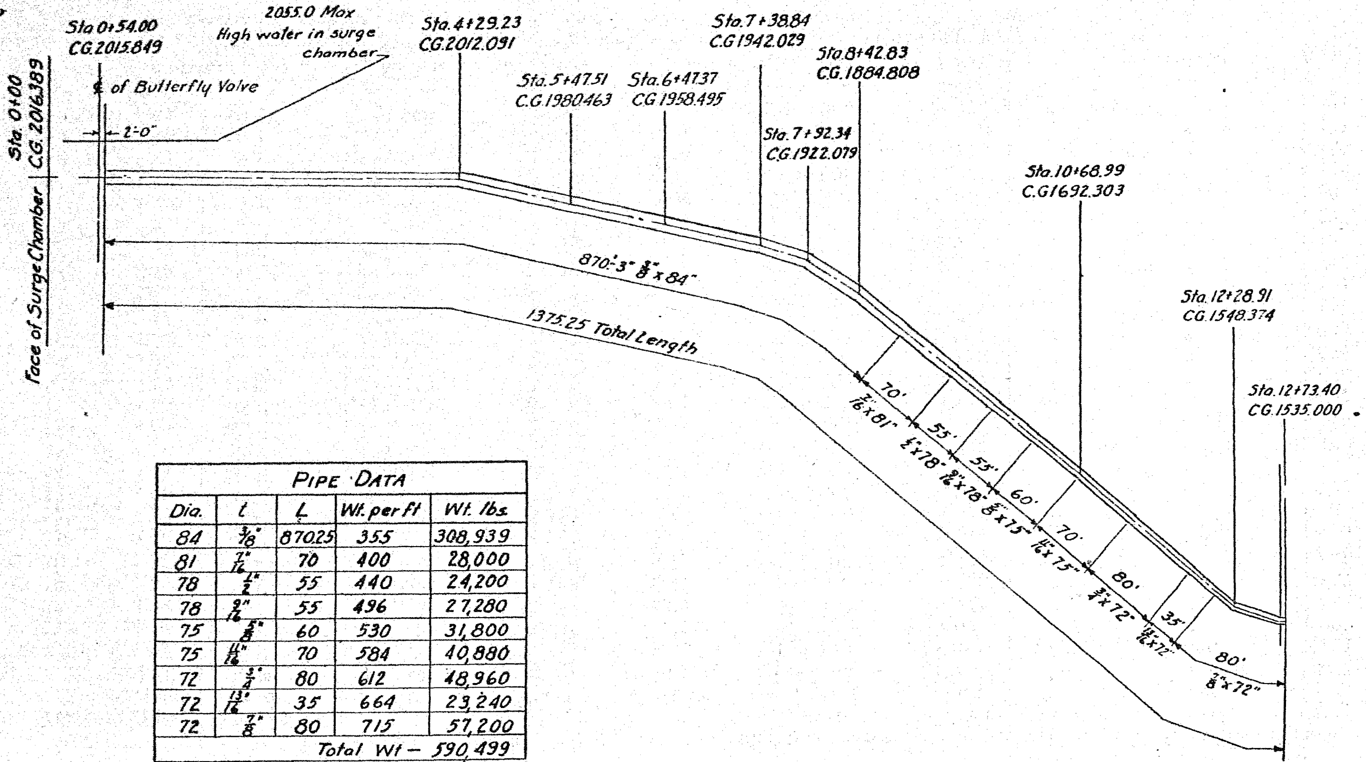
Table III—Value of Friction Loss Power

		Riveted Steel Penstock			Welded Steel Penstock			Welded Nickel Clad Steel Penstock		
Year	Cost Per Kw-Hr. in Mills	Average Head Loss	Kw-Hr. Loss Per Year	Value of Lost Power	Average Head Loss	Kw-Hr. Loss Per Year	Value of Lost Power	Average Head Loss	Kw-Hr. Loss Per Year	Value of Lost Power
1	5.80	6.2′	716,800	$ 4,157	4.54	524,900	$ 3,044	3.67′	424,300	$ 2,461
2	5.75	6.6′	763,000	4,387	4.96	571,100	3,284	"	"	2,440
3	5.70	7.0′	809,300	4,613	5.38	622,000	3,545	"	"	2,419
4	5.65	7.4′	855,500	4,834	5.81	671,700	3,795	"	"	2,397
5	5.60	7.8′	901,800	5,050	6.23	720,300	4,034	"	"	2,376
6	5.55	8.2′	948,000	5,261	6.65	768,800	4,267	3.67′	424,300	2,355
7	5.50	8.6′	994,200	5,468	7.08	818,500	4,502	"	"	2,334
8	5.45	9.0′	1,040,500	5,671	7.50	867,100	4,726	"	"	2,312
9	5.40	9.5′	1,098,300	5,931	7.92	915,600	4,944	"	"	2,291
10	5.35	9.9′	1,144,500	6,123	8.35	965,300	5,164	"	"	2,270
11	5.30	10.3′	1,190,800	6,311	8.77	1,013,900	5,374	3.67′	424,300	2,249
12	5.25	10.7′	1,237,000	6,494	9.19	1,062,500	5,578	"	"	2,228
13	5.20	11.1′	1,283,000	6,672	9.62	1,112,200	5,783	"	"	2,206
14	5.15	7.2′	832,400	4,287	5.77	667,100	3,436	"	"	2,185
15	5.10	7.5′	867,100	4,422	6.09	704,100	3,591	"	"	2,164
16	5.05	7.8′	901,800	4,554	6.41	741,100	3,743	3.67′	424,300	2,143
17	5.00	8.2′	948,000	4,740	6.73	778,100	3,891	"	"	2,122
18	4.95	8.5′	982,700	4,864	7.05	815,100	4,035	"	"	2,100
19	4.90	8.8′	1,017,400	4,985	7.37	852,000	4,175	"	"	2,079
20	4.85	9.2′	1,063,600	5,158	7.69	889,000	4,312	"	"	2,058
21	4.80	9.5′	1,098,300	5,272	8.01	926,000	4,445	3.67′	424,300	2,037
22	4.75	9.8′	1,133,000	5,382	8.33	963,000	4,574	"	"	2,015
23	4.70	10.2′	1,179,200	5,442	8.65	1,000,000	4,700	"	"	1,994
24	4.65	10.5′	1,213,900	5,645	8.97	1,037,000	4,822	"	"	1,973
25	4.60	10.8′	1,248,600	5,744	9.29	1,074,000	4,940	"	"	1,952

Table III—Value of Friction Loss Power—(Continued)

Year	Cost Per Kw-Hr. in Mills	Riveted Steel Penstock: Average Head Loss	Riveted Steel Penstock: Kw-Hr. Per Year	Riveted Steel Penstock: Value of Lost Power	Welded Steel Penstock: Average Head Loss	Welded Steel Penstock: Kw-Hr. Loss Per Year	Welded Steel Penstock: Value of Lost Power	Welded Nickel Clad Steel Penstock: Average Head Loss	Welded Nickel Clad Steel Penstock: Kw-Hr. Loss Per Year	Welded Nickel Clad Steel Penstock: Value of Lost Power
26	4.55	11.1′	1,283,300	$5,839	9.62	1,112,200	$5,061	3.67′	424,300	$1,931
27	4.50	7.2′	832,400	3,746	5.77	667,100	3,002	″	″	1,909
28	4.45	7.5′	867,100	3,859	6.09	704,100	3,133	″	″	1,888
29	4.40	7.8′	901,800	3,968	6.41	741,100	3,260	″	″	1,867
30	4.35	8.2′	948,000	4,124	6.73	778,100	3,385	″	″	1,846
31	4.30	8.5′	982,700	4,226	7.05	815,100	3,505	3.67′	424,300	1,824
32	4.25	8.8′	1,017,400	4,324	7.37	852,000	3,621	″	″	1,802
33	4.20	9.2′	1,063,600	4,467	7.69	889,000	3,734	″	″	1,782
34	4.15	9.5′	1,098,300	4,558	8.01	926,000	3,843	″	″	1,761
35	4.10	9.8′	1,133,000	4,645	8.33	963,000	3,948	″	″	1,740
36	4.05	10.2′	1,179,200	4,776	8.65	1,000,000	4,050	3.67′	424,300	1,718
37	4.00	10.5′	1,213,900	4,856	8.97	1,037,000	4,148	″	″	1,697
38	3.95	10.8′	1,248,600	4,932	9.29	1,074,000	4,242	″	″	1,676
39	3.90	11.1′	1,283,300	5,005	9.62	1,112,200	4,338	″	″	1,655
40	3.85	7.2′	832,400	3,205	5.77	667,100	2,568	″	″	1,634
41	3.80	7.5′	867,100	3,295	6.09	704,100	2,676	3.67′	424,300	1,612
42	3.75	7.8′	901,800	3,382	6.41	741,100	2,779	″	″	1,591
43	3.70	8.2′	948,000	3,508	6.73	778,100	2,879	″	″	1,570
44	3.65	8.5′	982,700	3,587	7.05	815,100	2,975	″	″	1,549
45	3.60	8.8′	1,017,400	3,663	7.37	852,000	3,067	″	″	1,527
46	3.55	9.2′	1,063,600	3,776	7.69	889.000	3,156	3.67′	424,300	1,506
47	3.50	9.5′	1,098,300	3,844	8.01	926,000	3,241	″	″	1,485
49	3.45	9.8′	1,133,000	3,909	8.33	963,000	3,322	″	″	1,464
49	3.40	10.2′	1,179,200	4,009	8.65	1,000,000	3,400	″	″	1,443
50	3.35	10.5′	1,213,900	4,067	8.97	1,037,000	3,474	″	″	1,421
Totals...................			51,758,700	$235,037		42,456,700	$195,511		30,543,700	$97,059

Saving of welded Nickel Clad Steel Penstock over Riveted Steel = 11,913,000 K.W.H. or $98,452.
Saving of welded Nickel Clad Steel Penstock over Welded Steel = 21,215,000 K.W.H. or $137,978.



PIPE DATA				
Dia.	t	L	Wt. per ft	Wt. lbs.
84	3/8"	870.25	355	308,939
81	7/16"	70	400	28,000
78	1/2"	55	440	24,200
78	9/16"	55	496	27,280
75	5/8"	60	530	31,800
75	11/16"	70	584	40,880
72	3/4"	80	612	48,960
72	13/16"	35	664	23,240
72	7/8"	80	715	57,200
			Total Wt —	590,499

Fig. 6. Main details of welded steel penstock.

Design of Welded Steel Penstock.—This pipe was designed at the time of the installation of the third unit and the quantities are taken directly from the original drawings.

For ease of comparison it is shown in its main details in Fig. 6. This line in its true location is of a slightly different length from that of the riveted pipe as originally installed, it is therefore assumed to be of the same length as the other line so that the costs will be on the same basis.

All sizes and weights are as shown on the tabulation in Fig. 6, its total weight, F.O.B. shop, being 590,499 lbs.

The costs of this line are as shown in Table IV.

Table IV—Welded Steel Penstock
Summary of Direct Costs

	Cost F.o.b. Shop	Overhead	Transportation	Field Costs plus Overhead Labor	Field Costs plus Overhead Material
Penstock	$33,954	$679	$2,953	....	....
Placing Penstock	....	....	....	$ 3,176	$ 422
Welding	....	....	31	3,317	918
Saddles	1.047	21	89	....	....
Butterfly Valve	6,208	124	217	323	35
Sandblasting Inside	....	....	....	1,501	379
Priming Inside	....	....	10	584	144
Enameling Inside	....	....	99	2,338	640
Painting Outside	....	....	20	1,774	578
	$41,209	$824	$3,419	$13,013	$3,116

Grand Total....................$61,581

Table V—Welded Steel Penstock
Maintenance Costs

CLEANING (Inside of pipe)			
29,091 sq. ft. @ 1.75¢/sq. ft.	Labor	=	$ 2,473
34% overhead on	Labor	=	841
29,091 sq. ft. @ 8.0¢/sq. ft.	Materials	=	145
10% overhead on	Materials	=	15
			$ 3,474
RE-PRIMING (Inside)			
29,091 sq. ft. @ 8.5¢/sq. ft.	Labor	=	$ 509
34% overhead on	Labor	=	173
100 gal. primer @ $1.80 per gal.		=	180
10% overhead on	Materials	=	18
2,000 lbs. @ .68¢/lb.	Transportation	=	14
			$ 894
RE-ENAMELING (Inside)			
29,091 sq. ft. @ .05¢/sq. ft.	Labor	=	$ 2,327
34% overhead on	Labor	=	791
5/8 lb. enamel per sq. ft. @ $80.00		=	727
per ton 10% overhead on	Materials	=	73
18,182 lbs. enamel @ .68¢/lb.	Transportation	=	124
			$ 4,042

$3,474
894
4,042

Total Cost $8,410 each 13 years

RE-PAINTING (Outside—1 coat)

29,424 sq. ft. @ 1.75¢/sq. ft.	Labor	=	$ 502
34% overhead on	Labor	=	171
29,424 sq. ft. @ .75¢/sq. ft.	Material	=	221
10% overhead on	Material	=	22
1,400 lbs. @ .68¢/lb.	Transportation	=	10
			$ 926

Yearly inspection and touch-up $ 50

TOTAL MAINTENANCE COSTS

Repainting outside each 7 years	= 6 x 926	=	$ 5,556
Yearly maintenance	= 44 x 50	=	2,200
Cleaning and Re-enameling each 13 years	= 3 x 8,410	=	25,230
		TOTAL	$32,986

Design of Riveted Penstock.—This pipe was designed at the time of the installation of the first two units and the quantities are taken directly from the original drawings.

For ease of comparison it is shown in its main details in Fig. 7.

All sizes and weights are as shown in the tabulation, the total weight, F.O.B. shop, being 710,733 lbs.

The costs of this line are as shown in Table VI.

Table VI—Riveted Steel Penstock
Summary of Direct Costs

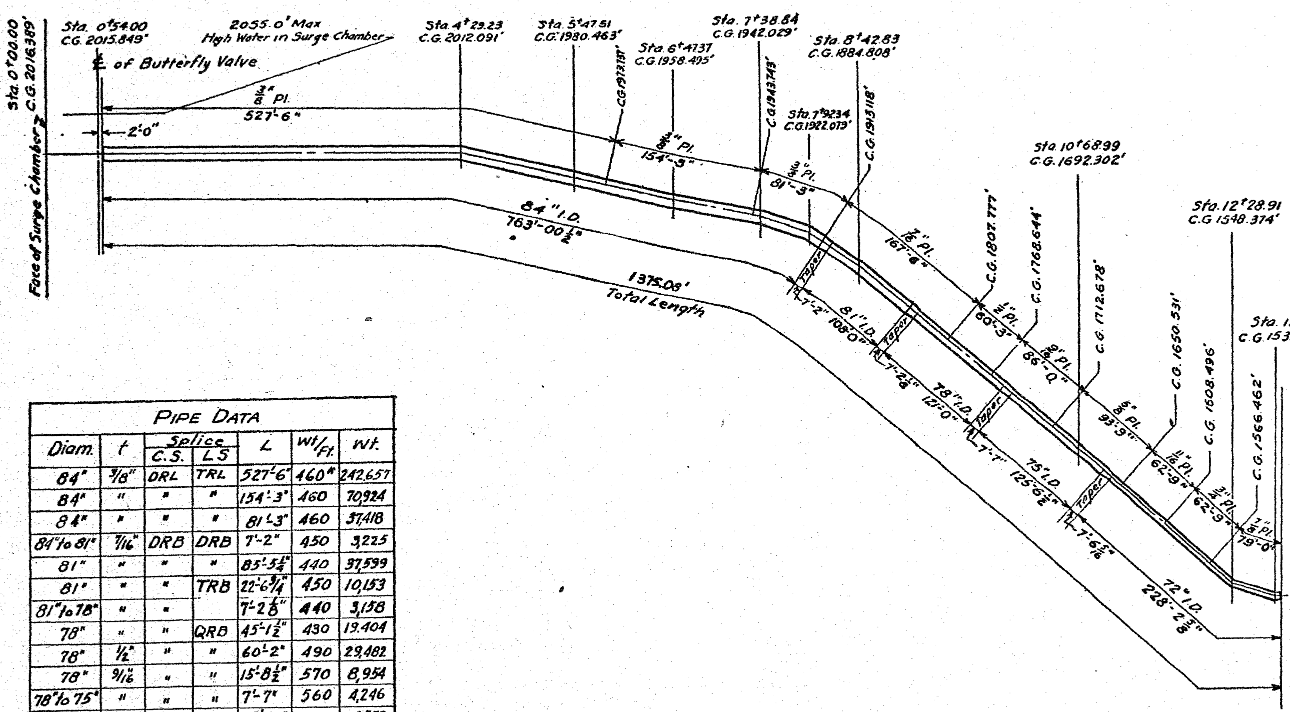
	Cost F.o.b. shop	Over-head	Transpor-tation	Field Costs plus Overhead Labor	Field Costs plus Overhead Material
Penstock	$41,436	$829	$4,840	....	....
Placing Penstock	....	....	....	$ 7,142	$ 938
Riveting	....	....	....	10,466	1,955
Caulking	....	....	....	2,571	234
Saddles	1,047	21	89	....	....
Butterfly Valve	6,208	124	217	323	35
Sandblasting Inside	....	....	....	1,688	408
Priming Inside	....	....	10	695	149
Enameling Inside	....	....	101	2,979	652
Painting Outside	....	....	27	1,809	1,091
	$48,691	$974	$5,284	$27,673	$5,462

Grand Total..$88,084

Table VII—Riveted Penstock
Maintenance Costs

CLEANING (Inside of pipe)

29,641 sq. ft. @ 9.75¢/sq. ft.	Labor	=	$ 2,890
34% overhead on	Labor	=	983
29,641 sq. ft. @ .75¢/sq. ft.	Materials	=	222
10% overhead on	Materials	=	22
			$ 4,117



Pipe Data						
Diam.	t	Splice C.S.	Splice L.S.	L	Wt/Ft.	Wt.
84"	3/8"	DRL	TRL	527'-6"	460#	242,657
84"	"	"	"	154'-3"	460	70,924
84"	"	"	"	81'-3"	460	37,418
84" to 81"	7/16"	DRB	DRB	7'-2"	450	3,225
81"	"	"	"	85'-5 1/4"	440	37,599
81"	"	"	TRB	22'-6 3/4"	450	10,153
81" to 78"	"	"		7'-2 1/8"	440	3,158
78"	"	"	QRB	45'-1 1/2"	430	19,404
78"	1/2"	"	"	60'-2"	490	29,482
78"	9/16"	"	"	15'-8 1/2"	570	8,954
78" to 75"	"	"	"	7'-7"	560	4,246
75"	"		"	62'-10"	550	34,558
75"	5/8"	"	"	62'-8 1/2"	600	37,625
75" to 72"	"	"	"	7'-6 5/16"	590	4,440
72"	"	"	"	23'-6 3/4"	580	13,667
72"	11/16"	"	"	62'-10"	650	40,841
72	3/4"	"	"	62'-10"	720	45,240
72"	7/8"	"	"	78'-11 3/8"	850	67,142
						Total Wt - 710,733#

Fig. 7. Main details of riveted penstock.

RE-PRIMING (Inside)

100 gal. primer @ $1.80 per gal.		=	$ 180
10% overhead on	Material	=	18
29,641 sq. ft. @ 2.00¢/sq. ft.	Labor	=	593
34% overhead on	Labor	=	201
2,000 lb. @ .68¢/lb.	Transportation	=	14
			$ 1,006

RE-ENAMELING (Inside)

29,641 sq. ft. @ .10¢/sq. ft.	Labor	=	$ 2,964
34% overhead on	Labor	=	1,008
¾lb. enamel per sq. ft. @ $80.00	per ton	=	889
10% overhead on	Material	=	89
22,231 lbs. enamel @ .68¢/lb.	Transportation	=	151
			$ 5,101

$ 4,117
1,006
5,101

Total Cost $10,224 each 13 years

RE-PAINTING (Outside—1 coat)

29,976 sq. ft. @ 2¢/sq. ft.	Labor	=	$ 600
34% overhead on	Labor	=	204
75 gal. paint @ $3.15 per gal.		=	236
10% overhead on	Material	=	24
1,500 lbs. @ .68¢/lb.	Transportation	=	10
			$ 1,074

Yearly inspection, caulking and touch up = $ 200

TOTAL MAINTENANCE COST

Repainting outside each 7 years = 6 x 1,074	=	$ 6,444
Yearly maintenance = 44 x 200	=	8,800
Cleaning and Re-enameling each 13 years = 3 x 10,224	=	30,672
TOTAL		$45,916

COMPARISON OF PENSTOCKS

	Welded Steel Pipe	Welded Nickel Clad Steel Pipe
Weight	590,499 lbs.	488,700 lbs.
First Cost	$ 61,581.00	$ 101,128.00
40 Year Interest	$ 44,272.00	$ 72,560.00
Maintenance	$ 32,986.00	$ 7,216.00
Total 50 year Cost	$138,839.00	$ 180,904.00
Power Loss	$195,511.00	$ 97,059.00
Power Saving of Nickel Clad Steel Line		$ 98,452.00
Actual Cost of Nickel Clad Steel Line		$ 82,452.00
50 Year Saving of Nickel Clad Steel Line over Welded Steel line		$ 56,387.00
Excess generating capacity of Nickel Clad Steel Line over rusted Welded Steel Line		183 kw.

Value of excess Kw. generating capacity		$ 20,130.00
Lost Peak Capacity during each shut-down for penstock cleaning	14,500 kw.	
Lost power during each shut-down for penstock cleaning	6,699,000 kw-hr.	
Earning Capacity of Kw-hrs. generated by excess capacity of Nickel Clad Steel Line		$ 86,248.00
Earning capacity of money spent in excess maintenance charges of Welded Steel Line	$ 20,773.00	
Excess first cost per kw. for a 14,500 kw. plant		$ 2.73

Salvage Value.—As previously mentioned, the condition of the plate composing the nickel penstock will be in practically the same condition at the end of the 50-year period as at the beginning, while the plain steel will have had three cleanings at which time at least 15% of its volume will have been converted into rust.

If at this time, or at the end of the 40-year amortization period, it would be found advisable to abandon the project, the steel pipe would have an extremely low scrap value as it would not be useful as plate. Using an 85% recovery at .4¢ per lb. it would bring $2,077.00, while the nickel line would have 100% recovery at about 5¢ per lb. which would bring $22,435.00.

As the nickel plate would also be useful for the fabrication of tanks, smaller lines or other containers or linings, it could be held as warehouse stock at a considerably higher valuation.

Intangible Advantages.—Together with advantages enumerated above, which are easily expressed in the usual manner in dollars, there are other intangible advantages whose exact financial value is difficult to arrive at.

The first is the value of the peak power of the nickel clad steel line which is ready to serve at all times and is never out of commission due to cleaning or repainting. This peak power may be of tremendous value on certain emergencies. As the unit of this penstock serves 14,500 kw. capacity, this amount of peaking capacity is lost to the system due to any shutdown caused by the penstock.

The second is the value of the power lost during a shutdown. As a cleaning and repainting job cannot be done in less than five weeks, the lost capacity of the plant due to one unit of 14,500 kw. out of service for such a length of time amounts to 6,699,000 kw-hr. at a load factor of 55%. On a system where hydro is carrying the base load and peaking is done by steam, it can be seen that this load becomes quite a costly burden in fuel if it should be found necessary to make it up in steam.

Thirdly, under some systems of cost accounting, the value of the power saved may be given a capital value, as it enhances the surplus balance at the end of the year. If this saving of power of the nickel

clad line over the welded line ($98,452.) should be so considered to be available to earn money for the system to be used for extension of services or increasing generating capacities at other plants, at a normal value of 3½% for money, this power saving will amount to an additional sum of $86,248.

Fourth, some firms capitalize major maintenance costs such as the cleaning and repainting jobs. If these items of the two lines in question are capitalized, they must be returned by the system the same as the first cost capital. If this is done, the excess interest charge during the fifty-year period of the major maintenance charges amounts to $20,773 more for the welded steel than the nickel clad steel pipe.

Fifth, the peak generating capacity with the turbine and generator running full load at 420 s.f. is 183 kw. greater for the nickel clad line. With an installed value of $110 per kw. this represents a generating capacity which would cost $20,130 to install.

While the above mentioned items are not usually used as methods of calculating losses and gains, they do represent an intangible value which cannot be correctly ascertained but which savings do show up in the long run in a well managed business where all advantages are seen and used. They appear in that final analysis of a firm as to whether it stands still or grows. Every increase of earning capacity at no additional expense or reduction of operating expenses releases capital for the further earning of money by other units of the system.

There is also another factor which demands consideration. Although both penstocks at the end of the forty-year amortization period have been paid for, they are still part of a system at the end of fifty years.

It is reasonable to assume that the need for hydro-electric generation will still exist at that time. The second term of years is now entered into with the possibility of two penstocks, the relative conditions of repair of which are sufficiently different to change the complexion of the future consideration of the project. On the one hand we have a steel penstock which has been cleaned of rust three times and therefore its wall section no longer has the entire factor of safety as originally installed. It has also gone for eleven years since an overhaul job and will need one in about two years. But on the other hand, the nickel clad line is still there in its entirety, its inner surface still capable of carrying the original quantity of water and all the original factor of safety still available.

This means that at the end of the period in question the nickel clad line is still able to function at no increased hazard and at its original efficiency at no additional cost, while the steel line is nearing the end of its productive life and is no longer able to produce its original output and is becoming a hazard to operate.

Summary.—Under "Comparison of Penstocks" a direct comparison in tabular form has been made. Although the nickel steel line weighs less than the steel line its first cost is $39,547.00 higher. The interest charges during the 40 year amortization period are also higher, this amount being $28,288.00.

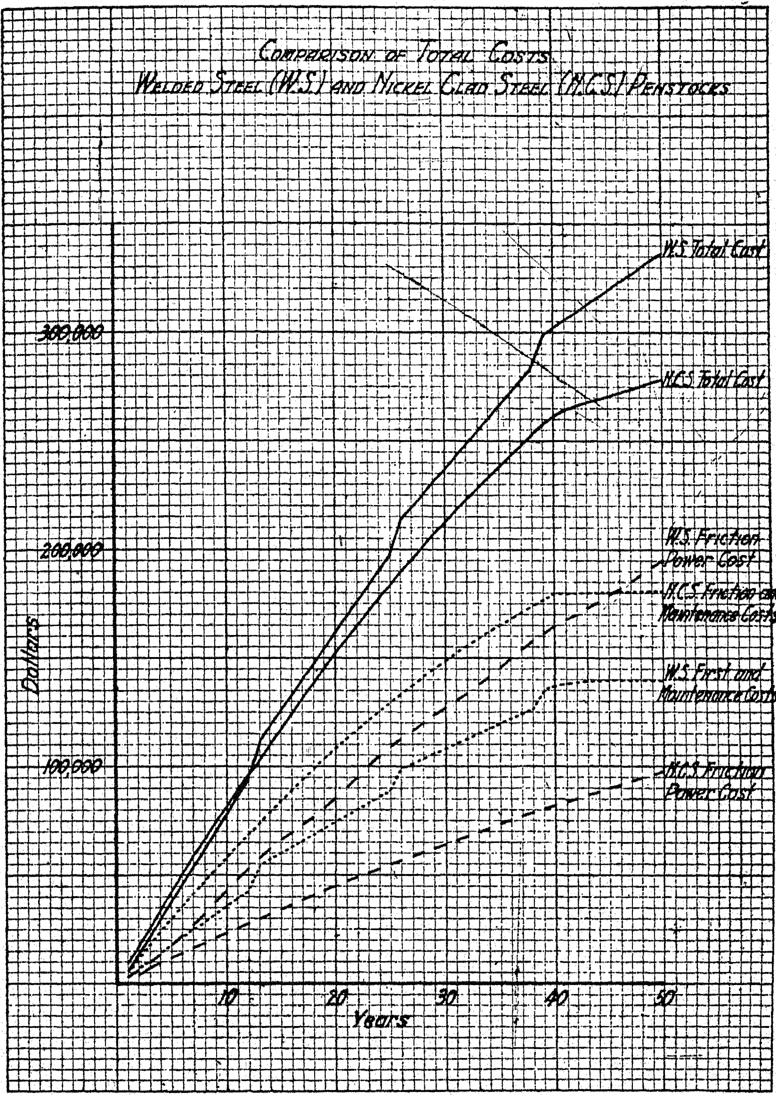


Fig. 8. Year-by-year comparison of sum of total costs, welded steel and welded nickel clad steel penstocks.

The sum of these two excesses is \$67,835.00. But from this point on, all other figures show the economy of the nickel line. The maintenance costs show a difference of \$25,770.00 in its favor, bringing the excess cost down to \$42,065.00.

The difference between the power losses due to penstock friction is \$98,452.00, which gain cancels the excess cost figure of \$42,065.00

and changes it to a gain of $56,387.00. Using these figures as a basis of comparison it can be seen that by an initial investment of $39,547.00 more, the nickel line by its reduced maintenance cost and greater generating possibilities costs $56,387.00 less for all those items regularly considered as first cost, variable and fixed charges.

This has reduced the actual cost of the nickel line to $82,452.00 in contrast to $138,839 for the steel line.

A year-by-year comparison of the sum of all first costs, interest, yearly retirement of capital payments and power loss was made and plotted in Fig. 8. From these curves it can be seen that at the twelfth year the total cost to date of the nickel line no longer is in excess of the steel line and from that time on the yearly costs are lower.

If credit for the 183 kw. of excess generating load capability is given in terms of $110 per kw. of installed cost, the sum of $20,130.00 can be taken from the last mentioned figure of $82,452.00. This can be justified, for with a growing system generation facilities are being constantly increased and this new line will contribute toward this continual growth.

The maintenance costs of the two lines show a difference of $25,770.00 in favor of the nickel clad line. If this money which need not be withdrawn from operating surplus, is available for other betterments and extensions of the system it may be considered to be capital surplus and during the period under investigation can earn at 3½%, $20,773.00.

The nickel line due to its lower friction loss has a capacity under the load conditions used, of generating $98,452.00 worth of power more than the steel line, as above noted. As this money adds to the yearly surplus, and may also be considered to be an increase of capital surplus, in like manner it can earn at 3½%, $86,248.00.

It is, therefore, evident in spite of a greater first cost investment of $39,547.00 and a greater interest cost of $28,288.00, that the nickel clad steel line balances this greater cost by means of increased savings and reduced losses so that the two types of pipes are on the same basis at the end of the twelfth year, and that by the end of the fifty-year period the nickel line has cost less by a minimum figure of $56,387.00 than the steel line. If the earning capacities of the above mentioned sums which are released to increase the capital surplus due to more efficient operation are taken into consideration the line will not only cost less than the steel line but will pay for itself instead of being amortized and supported by revenue from the system as a whole.

Conclusion.—The total amount of first cost, interest on first cost, maintenance and power losses show a saving of $56,387.00 on an excess installed value of $39,547.00, which represents the difference between $101,128.00 and $61,581.00. This is the fundamental economic figure which will completely justify the adoption of nickel clad steel in penstock construction.

The average head loss of the welded steel line is 1.50% against .79% for the nickel clad steel line, a saving of .71%. If these penstocks were generally adopted, each plant's generating capacity would be increased by .71%. With a kw. of installed capacity worth $110, each

100,000 kw. of hydro-electric installation would be enhanced by \$781,000.00 at a cost of \$2.73 for kw. of excess first costs, which is a first cost of \$273,000. This shows a return of 286.1% on the original excess investment based on generating capability.

To this is added a power saving of \$98,452.00 for a 14,500 kw. plant, which is \$6.79 per kw. installed capacity or \$679,000.00 for each 100,000 kw. over a 50 year period.

The lost power during each cleaning shut down is 6,699,000 kw-hr. or 19,097,000 kw-hr. during 50 years, which is 1,317 kw-hr. per kw. of installed capacity. This represents a total of 131,700,000 kw-hr. for each 100,000 kw. installed capacity which must be made up by some other plant, generated at fuel expense by steam or bought.

The service life has been increased from one of a doubtful period of time to one which may well be termed indefinite. Its increased efficiency has been shown above to be sufficient to prove it to be a sound business investment. Its general economy of operation, due to its greatly reduced maintenance costs and increased output, has been shown to be self sustaining. Its social advantages are great. Insofar as the penstock as a unit of a hydro-electric generating plant is concerned, it is ready to serve at a constant efficiency with no interruption which may be due to its special characteristics. As the water is used for domestic purposes in most projects, and particularly in the one under consideration, the quality of the water will be improved due to its rustless nature and freedom from sludge.

Chapter IX—Welded Pipe Lines for Paper Board Cylinder Machine

By Sumner E. Perkins,
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Paper board is made from wood pulp, old newspapers, magazines, and mixed waste papers. The raw materials are immediately broken down into a pulpy mass with the use of water and mechanical action. The pulpy, watery mass is pumped and piped through the various pieces of stock preparation equipment and storage tanks to the paper machine where the fibres of paper stock are separated from the water and the continuous sheet of paper board is made.

This report covers the welding and installation of the various water and paper stock pipe lines which are necessary for the making of paper board.

Fig. 1 is a photograph of part of the network of pipe lines, after installation was completed.

Figs. 2, 3 and 4 are working drawings of some special fittings and manifolds which were fabricated and installed.

The company installed a seven cylinder paper board machine for the manufacture of miscellaneous box boards. In order to reduce the

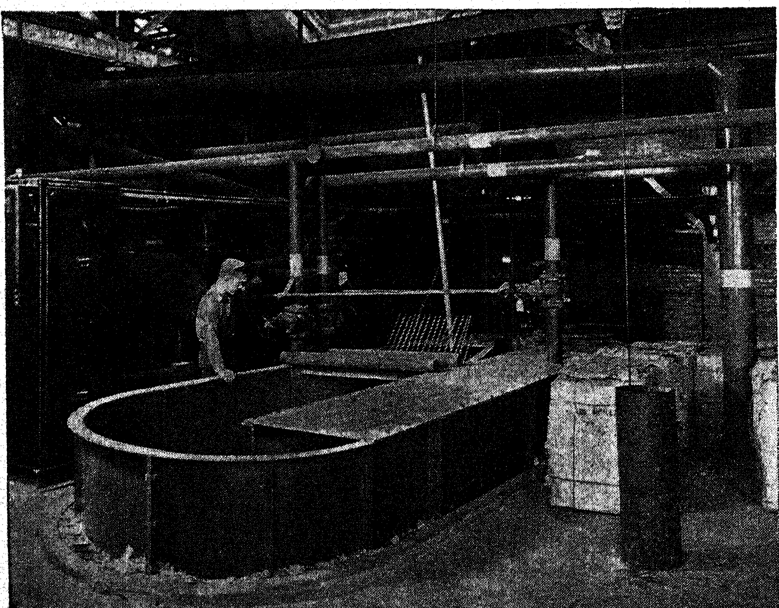


Fig. 1. Network of arc welded pipe lines.

cost of installation and facilitate the ease of installation, it was decided to substitute welding for the otherwise necessary flanges and fittings, in the fabrication of pipe lines, where it was practical to do so. Threaded pipe was used only for size 2″ and smaller.

Unfortunately, there were no detailed records kept of piping costs from which could be determined the resulting savings due to the application of welding methods. Therefore, this report is based upon an actual survey, made by the writer, of welded joints, cost statistics presented in the "Procedure Handbook of Arc Welding Design and Practice," pages 92, 148, 717, and 718, and actual cost of materials.

With the basis of calculation as described above, it has been determined that the proportionate cost saving of welded joints and welded fittings over flanged joints and cast iron fittings is 84.8%. The cost of flanged joints and cast iron fittings would have been $6,235.94. The cost of welded joints and welded fittings was $950.72. The cost saving of welded joints and welded fittings over flanged joints and cast iron fittings was $5,285.22.

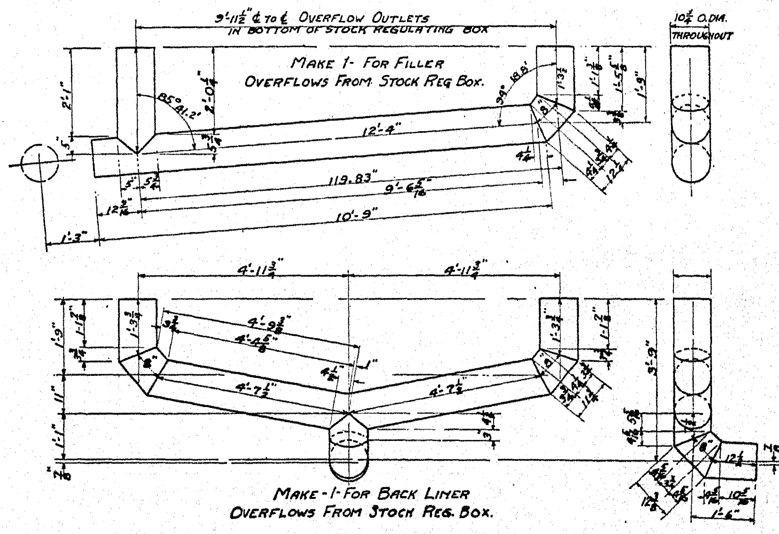


Fig. 2. Working drawing of pipe fitting fabricated by arc welding.

According to the bureau of Foreign and Domestic Commerce, the paper mills of the United States in 1935 were equipped with 967 Fourdrinier paper machines, 281 cylinder machines, and 263 of other types of paper machines. As far as we have been able to determine, no other complete cylinder board machine was installed last year besides the one which is the subject of this paper. Also, we have no other information on the number of cylinder paper machines installed in the United States than that for 1935 obtained from the bureau of Foreign and Domestic Commerce. Therefore, we will base our calculations of the gross savings accruing to industry on the Report for 1935 mentioned above.

Not all of the 281 cylinder machines reported in paper mills in 1935

were equipped with seven cylinders. The number of cylinders would vary from one to eight and would be of various face widths. Both of these paper machine characteristics will alter the quantity and size of pipe lines installed. The layout of the plant will also affect the cost of piping installation.

However, to obtain an estimate of the gross savings accruing to industry if the 281 cylinder machines mentioned above were installed with welded pipe lines instead of pipe lines joined with flanges and cast iron fittings, we will assume an average of three cylinders per paper machine to compensate for variations in number of cylinders, in cylinder face widths, in paper machine capacity, and in piping layout.

Under the conditions mentioned above, the gross savings accruing to industry would be $5,285.22 times 281 paper machines divided by seven cylinders times three cylinders, or $636,000.00, if all cylinder paper machines were installed with welded pipe lines.

The weakest point in a pipe line is at the root of the threads cut for the joint. As a welded pipe line requires no threads, its resistance to corrosion and strength is uniform throughout its entire length and can be measured by the thickness of the pipe. The thickness of an unthreaded pipe is 43% to 96% greater than the thickness of a threaded pipe at the root of the thread, depending upon the size of pipe.

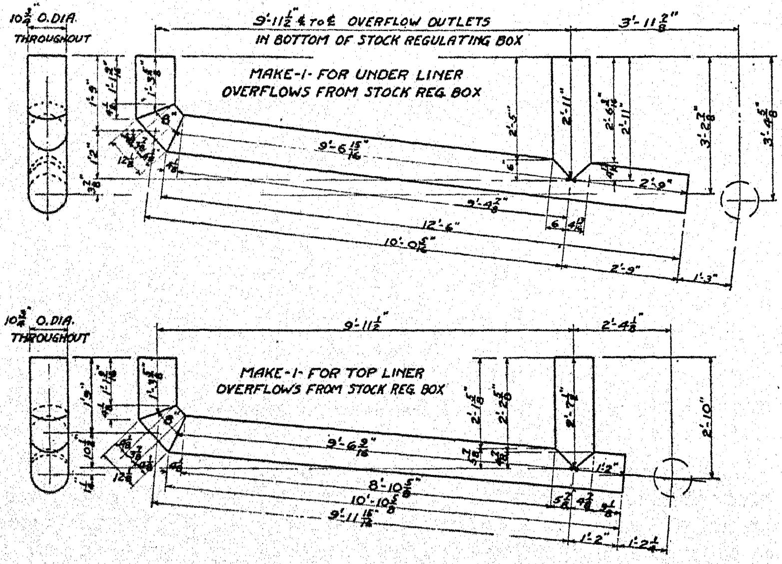


Fig. 3. Arc welded pipe fitting—working drawing.

Therefore, welding increases the service life of a pipe line by at least 43%. That is, a threaded pipe line installation which requires replacement every ten years, would have a life of at least fourteen years if the joints were welded.

The efficiency of a pipe line is increased slightly by welding if the

installation is well fabricated. The ring cavities at the joints of a threaded pipe line are eliminated by properly beveling and matching the pipe ends for welding. This advantage of a welded pipe line, however, can be lost by poor workmanship that allows the weld metal to drop through the joint and form a constricting ring inside the pipe. A good welder and fabricator can prevent the formation of this constricting ring.

The general economy of a welded pipe line, such as the subject of this paper, is due to reduction of labor cost for installation, elimination of costly cast iron fittings, and ease of installation. The extreme flexibility of the welding process for pipe line installations permits locating the pipe so as to take up the least amount of space, thereby increasing the amount of space available for operating and maintaining adjacent and pertinent equipment. The elimination of bulky cast iron fittings, and screwed or flanged and bolted joints reduces the working space necessary for the installation of the pipe line. It is possible to install a welded pipe in a location that will not accommodate one which is screwed or flanged.

Therefore, the general economy of a welded pipe line is realized in reduced cost of plant additions (which, also, might otherwise not be possible), or in increased space for process operations (which is important in paper mills inherently congested with pipe lines), or in reduced size and cost of building additions.

The social advantage provided to mankind by welding pipe lines is exemplified by a neater and cleaner appearance of the installation which promotes good housekeeping and a higher level of moral thinking and responsibility on the part of the workmen. A man's thoughts and actions are greatly influenced by his working environment and conditions. Whereas, a screwed or flanged pipe line presents an awkward and bulky appearance, the smooth and unobtrusive appearance of the welded pipe line incites the workman's pride in his plant and in his work.

Organization of the Work.—The layout and installation of piping was under the supervision of the chief mechanical engineer. The fabrication and welding of the pipe lines was under the direction of the master mechanic who was in direct charge of the workmen.

The work was divided into two eight hour shifts. The day shift, with the master mechanic as foreman, cut the pipe sections to required lengths, welded on necessary flanges, cut ends of pipes to required angles, prefabricated welded elbows, tees, and special fittings, and tack welded, into place, the various pipe sections and fittings. The night shift, under the supervision of a sub-foreman, finish-welded all joints.

Methods.—Depending upon the particular problems involving the installation, pipe lines and sizes were either indicated on schematic diagrams or definitely located on the installation drawings.

All pipes were cut to length, with the required joint angles, by acetylene torches.

The pipes were tacked in place with the electric arc by the day shift.

All special fittings and joints were fabricated by the day shift with the electric arc.

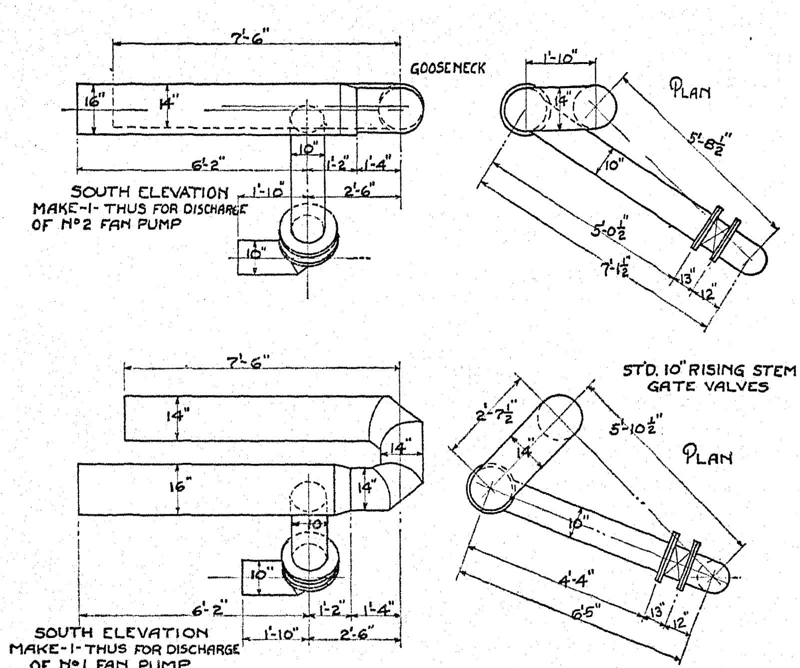


Fig. 4. Details of pipe fitting fabricated by arc welding.

All pipes and fittings, which were tacked together by the day shift, were finished-welded by the night shift with the electric arc.

All elbows were fabricated out of standard steel pipe, except those furnished as part of the paper mill equipment. Each elbow was made with two forty-five degree angle cuts.

Costs.—No detailed cost records were kept of the piping installation, which would permit us to determine the cost of welding the pipe lines. Therefore, the costs and savings submitted in this report are based on the total number of welded joints, the estimated number of flanges and cast iron fittings required if the pipe line were not welded, and the cost data presented in "Procedure Handbook of Arc Welding Design and Practice."

The actual data obtained by the writer on his survey of the installed pipe lines, and the resulting calculations and tabulations for the determination of costs and savings, are presented in the following tabulations.

Those flanged or screwed joints which are necessary for connection to valves or other pieces of equipment or machines have not been included in the survey.

The number of welded joints do not coincide with the otherwise required number of flanged joints, as short pieces of pipe were utilized in the welded pipe lines, whereas, for a flanged pipe line, standard lengths of pipe would generally be used. Also, the welded joints required for fabrication of elbows and fittings are included in the survey

of pipe lines, for which would be substituted cast iron elbows and cast iron fittings in flanged pipe lines.

The cost figures in this report cover only the material and labor required to make the joints and fittings.

MATERIAL COST FOR WELDED JOINTS AND FITTINGS

Nominal Pipe Size in Inches	Length of Installed Pipe in Feet	Cost of Pipe Per Foot	Length of Pipe Req'd Per Welded 90° Elbow in Feet	Total Number of 90° Elbows	Total Length of Pipe Required for 90° Elbows
2	....	$0.12	0	0	0
3	155	0.25	0.75	8	6
4	1053	0.34	0.92	58	53
5	20	0.47	1.08	0	0
6	602	0.65	1.16	47	55
8	1220	0.85	1.25	58	73
10	645	1.38	1.50	46	69
12	163	1.99	1.67	9	15
14	144	1.81	2.00	5	10

Nominal Pipe Size in Inches	Length of Pipe Req'd per Welded Tee in Feet	Total Number of Tees	Total Length of Pipe Required for Tees	Length of Pipe Req'd per 45° Welded Elbow in Feet	Total Number of 45° Elbows
2	0	0	0	0	0
3	1.33	0	0	0.50	0
4	1.67	16	27	0.67	13
5	1.88	0	0	0.75	2
6	2.00	6	12	0.83	10
8	2.25	23	52	0.92	47
10	2.75	4	11	1.08	14
12	3.00	0	0	1.25	5
14	3.50	0	0	1.25	0

Nominal Pipe Size in Inches	Total Length of Pipe Required for 45° Elbows	Total Length of Pipe Required for Special Fittings	Total Pipe Required for All Fittings in Feet	Total Cost of Pipe for Fittings
2	0	0.68	1	$ 0.12
3	0	1.40	8	2.00
4	8.70	14.83	104	35.36
5	1.50	0	2	0.94
6	8.30	40.35	116	75.30
8	43.40	31.95	201	170.85
10	15.10	10.70	106	146.08
12	6.25	6.34	28	55.66
14	0	11.70	22	39.82
			Total	$526.13

Nominal Size of Special Fittings in Inches		Total Number of Special Fittings	Length of 2" Pipe Req'd per Fitting in Feet	Length of 3" Pipe Req'd per Fitting in Feet	Length of 4" Pipe Req'd per Fitting in Feet	Length of 6" Pipe Req'd per Fitting in Feet
8 x 12 x 90°	Ell	1	0	0	0	0
10 x 10 x 8	Tee	2	0	0	0	0
12 x 12 x 10	Tee	1	0	0	0	0
4 x 4 x 6	Tee	2	0	0	1.34	0.67
4 x 4 x 2	Tee	4	0.17	0	1.08	0
8 x 8 x 4	Tee	12	0	0	0.54	0
6 x 6 x 4	Tee	1	0	0	0.54	1.34
14 x 14 x 10	Tee	2	0	0	0	0
8 x 6 x 6	Tee	5	0	0	0	4.29
6 x 4 x 90°	Ell	2	0	0	0.27	0.67
8 x 8 x 6	Tee	4	0	0	0	0.75
8 x 6 x 90°	Ell	5	0	0	0	0.50
14 x 12 x 90°	Ell	2	0	0	0	0
14 x 14 x 12	Tee	2	0	0	0	0
8 x 4 x 90°	Ell	1	0	0	0.27	0
6 x 6 x 3	Tee	7	0	0.20	0	1.34
10 Cross		1	0	0	0	0

Nominal Size of Special Fittings in Inches		Length of 8" Pipe Req'd per Fitting in Feet	Length of 10" Pipe Req'd per Fitting in Feet	Length of 12" Pipe Req'd per Fitting in Feet	Length of 14" Pipe Req'd per Fitting in Feet
8 x 12 x 90°	Ell	0.35	0	1.00	0
10 x 10 x 8	Tee	0.92	1.84	0	0
12 x 12 x 10	Tee	0	1.00	2.00	0
4 x 4 x 6	Tee	0	0	0	0
4 x 4 x 2	Tee	0	0	0	0
8 x 8 x 4	Tee	1.50	0	0	0
6 x 6 x 4	Tee	0	0	0	0
14 x 14 x 10	Tee	0	1.17	0	2.34
8 x 6 x 6	Tee	0.25	0	0	0
6 x 4 x 90°	Ell	0	0	0	0
8 x 8 x 6	Tee	1.50	0	0	0
8 x 6 x 90°	Ell	0.75	0	0	0
14 x 12 x 90°	Ell	0	0	0.50	1.17
14 x 14 x 12	Tee	0	0	1.17	2.34
8 x 4 x 90°	Ell	00.75	0	0	0
6 x 6 x 3	Tee	0	0	0	0
10 Cross		0	3.68	0	0

Nominal Pipe Size in Inches	Size of Welding Electrode Used in Inches	Pounds of Electrode per Joint	Total Number of Welded Joints	Total Pounds of Electrode Used	Cost of W-20 Electrode per Pound
2	5/32	0.35	4	1.40	$0.115
3	5/32	0.44	23	8.80	0.115
4	5/32	0.64	225	133.20	0.115
5	5/32	0.81	3	3.24	0.115
6	3/16	0.96	175	156.80	0.105
8	3/16	1.33	338	352.10	0.105
10	3/16	1.65	174	237.90	0.105
12	1/4	2.00	51	72.00	0.105
14	1/4	2.30	34	29.90	0.105

Nominal Pipe Size in Inches	Total Cost of Welding Electrode	K.W.H. Per Joint	Total K.W.H. Required for Welding	Unit Cost per K.W.H.	Generator Efficiency
2	$ 0.16	0.31	1.24	$0.0066	61%
3	1.01	0.38	8.74	0.0066	61%
4	15.32	0.53	119.25	0.0066	61%
5	0.37	0.66	1.98	0.0066	61%
6	16.43	0.79	138.25	0.0066	61%
8	37.00	1.19	402.22	0.0066	61%
10	24.98	1.47	255.78	0.0066	61%
12	7.55	1.77	90.27	0.0066	61%
14	3.14	2.09	71.06	0.0066	61%
Total	$105.96				

Nominal Pipe Size in Inches	Total Cost of K.W.H. Consumed	Circumference of Pipe in Feet	Total Number of Flame Cuts Required for Fittings	Total Feet of Flame Cut
2	$ 0.01	0.64	4	3
3	0.09	0.98	108	106
4	1.29	1.18	240	283
5	0.02	1.28	4	5
6	1.50	1.77	217	384
8	4.35	2.26	352	795
10	2.76	2.85	186	530
12	0.98	3.34	46	154
14	0.77	3.63	23	84
Total	$11.77			

Nominal Pipe Size in Inches	Thickness of Pipe in Inches	Gas Cost of Flame Cut in Dollars per Foot
2	$\frac{5}{32}$	$ 0.005
3	$\frac{7}{32}$	0.005
4	$\frac{15}{64}$	0.005
5	$\frac{1}{4}$	0.005
6	$\frac{9}{32}$	0.005
8	$\frac{5}{16}$	0.007
10	$\frac{5}{16}$	0.007
12	$\frac{3}{8}$	0.01
14	$\frac{3}{8}$	0.01

Nominal Pipe Size in Inches	Total Cost of Gas for Flame Cut	Total Material Cost including K.W.H., for Welded Joints and Fittings
2	$ 0.02	$ 0.31
3	0.53	3.63
4	1.41	53.38
5	0.03	1.36
6	1.92	95.15
8	5.56	217.76
10	3.72	177.54
12	1.59	65.73
14	0.84	44.57
Total	$15.57	$659.43

High quality reconditioned pipe was available on the local market. As this material was suitable for the installation, it was universally used, which explains the low cost of pipe presented in the above tabulations.

LABOR COST FOR WELDED JOINTS AND FITTINGS

Nominal Pipe Size in Inches	Actual Welding Time per Joint in Minutes	Total Welding Time in Hours	Labor Cost per Hours	Total Cost of Labor for Welding
2	5.5	0.37	$0.925	$ 0.34
3	7.0	2.68	0.925	2.48
4	9.0	33.80	0.925	31.30
5	11.3	0.57	0.925	0.53
6	13.5	39.38	0.925	36.40
8	17.8	100.10	0.925	92.60
10	22.0	63.80	0.925	59.00
12	26.5	22.58	0.925	20.81
14	31.3	17.75	0.925	16.40
		Total		$259.86

Nominal Pipe Size in Inches	Speed of Flame Cut in Feet per Hr.	Time in Hours Required For Total Feet of Flame Cut	Factor for Fatigue and Set Up	Adjusted Time in Hours Required Total Feet of Flame Cut
2	130	0.02	2	0.04
3	130	0.82	2	1.64
4	125	2.26	2	4.52
5	122	0.04	2	0.08
6	120	3.20	2	6.40
8	118	6.74	2	13.48
10	118	4.50	2	9.00
12	115	1.34	2	2.68
14	115	0.73	2	1.46

Nominal Pipe Size in Inches	Hourly Rate for Labor to Flame Cut	Total Cost of Labor to Flame Cut	Total Labor Cost for Welded Joints and Fittings
2	$0.80	$ 0.03	$ 0.37
3	0.80	1.31	3.79
4	0.80	3.62	34.92
5	0.80	0.06	0.59
6	0.80	5.12	41.52
8	0.80	10.78	103.38
10	0.80	7.20	66.20
12	0.80	2.14	22.95
14	0.80	1.17	17.57
	Total.................	$31.43	$291.29

TOTAL COSTS FOR WELDED JOINTS AND FITTINGS

Nominal Pipe Size in Inches	Total Material Cost for Welded Joints and Fittings	Total Labor Cost for Welded Joints and Fittings	Total Cost of Welded Joints and Fittings
2	$ 0.31	$ 0.37	$ 0.68
3	3.63	3.79	7.42
4	53.38	34.92	88.30
5	1.36	0.59	1.95
6	95.15	41.52	136.67
8	217.76	103.38	321.14
10	177.54	66.20	243.74
12	65.73	22.95	88.68
14	44.57	17.57	62.14
Total........	$659.43	$291.29	$950.72

Division of Cost	Cost	Percent of Total
Pipe for Fittings	$526.13	55.4
Welding Electrode	105.96	11.2
K. W. H.	11.77	1.2
Gas for Flame Cut	15.57	1.6
Labor for Welding	259.86	27.3
Labor for Flame Cut	31.43	3.3
Total	$950.72	100.0

MATERIAL COST FOR CAST IRON FITTINGS

Nominal Size of Special Fittings in Inches	Unit Cost of Cast Iron Fittings	Total Cost of Cast Iron Fittings
8 x 12 x 90° Ell	$38.64	$ 38.64
10 x 10 x 8 Tee	23.25	46.50
12 x 12 x 10 Tee	33.41	33.41
4 x 4 x 6 Tee	9.56	19.12
4 x 4 x 2 Tee	5.90	23.60
8 x 8 x 4 Tee	14.67	176.04
6 x 6 x 4 Tee	9.56	9.56
14 x 14 x 10 Tee	48.80	97.60
8 x 6 x 6 "Y"	22.11	110.55
6 x 4 x 90° Ell	10.84	21.68
8 x 8 x 6 Tee	14.67	58.68
8 x 6 x 90° Ell	16.77	83.85
14 x 12 x 90° Ell	48.31	96.62
14 x 14 x 12 Tee	48.80	97.60
8 x 4 x 90° Ell	16.77	16.77
6 x 6 x 3 Tee	9.56	66.92
10 Cross	31.11	31.11
	Total	$1028.25

Nominal Pipe Size in Inches	Unit Cost of Cast Iron 90° Elbows	Total Cost of Cast Iron 90° Elbows	Unit Cost of Cast Iron Tees	Total Cost of Cast Iron Tees
2	$	$ 0	$	$ 0
3	2.72	21.76	4.00	0
4	3.60	209.00	5.24	83.74
5	4.75	0	6.94	0
6	5.83	274.00	8.49	50.94
8	8.90	516.00	12.98	298.00
10	14.20	652.00	20.60	82.40
12	20.30	182.80	29.50	0
14	29.60	148.00	42.90	0
Total		$2003.56		$515.08

Nominal Pipe Size in Inches	Unit Cost of Cast Iron 45° Elbows	Total Cost of Cast Iron 45° Elbows	Total Cost of Cast Iron Fittings
2	$ 0	$ 0	$ 0
3	2.94	0	21.76
4	3.93	51.00	343.74
5	5.17	10.34	10.34
6	6.31	63.10	388.04
8	9.30	437.00	1251.00
10	14.88	208.00	942.40
12	21.25	106.25	289.05
14	29.60	0	148.00
Special Fittings	-------	-------	1028.25
Total		$875.69	$4422.58

MATERIAL AND LABOR COST FOR FLANGED JOINTS

Nominal Pipe Size in Inches	Total Number of Flanged Joint Otherwise Required	Total Cost per Flanged Joint	Total Material and Labor Cost for Flanged Joints
2	4	$ 0.80	$ 3.20
3	20	2.00	40.00
4	208	2.50	520.00
5	4	3.05	12.20
6	163	3.75	610.00
8	265	4.75	1259.00
10	144	7.25	1042.00
12	36	9.05	326.00
14	13	11.00	143.00
		Total	$3955.40

Total material and labor cost for flanged joints includes two companion flanges, one gasket, one set of bolts, labor to cut and thread pipe ends, and labor to assemble.

The total number of flanged joints otherwise required includes those joints made with cast iron fittings. Each cast iron fitting eliminates the cost of one pair or more of companion flanges and necessary pipe threading. The cost of flanged joints must be corrected accordingly. We will assume that sixty percent of the difference between the total cost of flanged joints and the cost of companion flanges represents the labor cost for pipe threading, which will be a close approximation.

Nominal Pipe Size in Inches	Unit Cost of Cast Iron Companion Flanges	Flange Deductions for 90° Elbows	Flange Deductions for Tees	Flange Deductions for 45° Elbows	Total Flange Deductions for Fittings
2	$0.26	0	4	0	4
3	0.63	16	0	0	16
4	0.91	119	87	26	232
5	1.04	0	0	4	4
6	1.26	101	44	20	165
8	1.92	123	162	94	379
10	2.78	92	41	28	161
12	3.86	21	3	10	34
14	5.23	12	4	0	16

Nominal Pipe Size in Inches	Total Cost of Flanges Deducted	Total Equivalent Flanged Joints Deducted (One half of Deducted Flanges)	Installed Cost of Equivalent Flanged Joints	Installed Cost Minus Flanges Deducted
2	$ 1.04	2	$ 1.60	$ 0.56
3	10.10	8	16.00	5.90
4	211.00	116	290.00	79.00
5	4.16	2	6.10	1.94
6	208.00	83	311.90	103.90
8	726.00	190	901.00	175.00
10	447.00	81	587.00	140.00
12	131.20	17	153.80	22.60
14	83.50	8	88.00	4.50
Total	$1822.00			

Nominal Pipe Size in Inches	60% of Difference to be deducted for Pipe Threading Not Necessary on Joints	Total Deductions for Flanges and Pipe Threading	Corrected Total Cost of Material and Labor for Flanged Joints
2	$ 0.34	$ 1.38	$ 1.82
3	3.54	13.64	26.36
4	47.40	258.40	261.60
5	1.16	5.32	6.88
6	62.34	270.34	339.66
8	105.00	831.00	428.00
10	84.00	531.00	511.00
12	13.56	144.76	181.24
14	2.70	86.20	56.80
Total	$320.04	$2142.04	$1813.36

TOTAL COST FOR CAST IRON FITTINGS AND FLANGED JOINTS

Nominal Pipe Size in Inches	Total Cost of Cast Iron Fittings	Corrected Total Cost of Material and Labor for Flanged Joints	Total Cost for Cast Iron Fittings and Flanged Joints
2	$ 0	$ 1.82	$ 1.82
3	21.76	26.36	48.12
4	343.74	261.60	605.34
5	10.34	6.88	17.22
6	388.04	339.66	727.70
8	1251.00	428.00	1679.00
10	942.40	511.00	1453.40
12	289.05	181.24	470.29
14	148.00	56.80	204.80
Special Fittings	1028.25	0	1028.25
Total	$4422.58	$1813.36	$6235.94

Total Cost for Cast Iron Fittings and Flanged Joints............$6235.94
Total Cost for Welded Fittings and Joints............950.72

Savings due to Welded Fittings and Joints $5285.22
Proportionate Cost Savings:

$$\frac{5285.22}{6235.94} \times 100 = \text{............} 84.8\%$$

CALCULATIONS FOR INCREASED SERVICE LIFE

Nominal Standard Pipe Size in Inches	Thickness of Pipe in Inches	Outside Diameter of Pipe in Inches	Pitch Diameter of Pipe Thread at end of Female Thread in Inches	Depth of Thread in Inches	Root Diameter of Pipe Thread at end of Female Thread in Inches
2	0.154	2.375	2.296	0.070	2.226
3	0.216	3.500	3.389	0.100	3.289
4	0.237	4.500	4.387	0.100	4.287
5	0.258	5.563	5.449	0.100	5.349
6	0.280	6.625	6.506	0.100	6.406
8	0.322	8.625	8.500	0.100	8.400
10	0.365	10.750	10.621	0.100	10.521
12	0.375	12.750	12.618	0.100	12.518
14	0.375	14.000	13.873	0.100	13.773

Nominal Pipe Size in Inches	Inside Diameter of Pipe in Inches	Thickness of Pipe at Root of Thread at End of Female Thread in Inches	Difference in Thickness of Threaded and Unthreaded Pipe in Inches	Present Increase in Thickness of Unthreaded Pipe over Threaded Pipe
2	2.067	0.080	0.074	94
3	3.068	0.110	0.106	96
4	4.026	0.131	0.106	81
5	5.047	0.151	0.107	71
6	6.065	0.171	0.109	64
8	7.981	0.210	0.112	53
10	10.020	0.250	0.115	46
12	12.000	0.259	0.116	45
14	13.250	0.262	0.113	43

Chapter X—Elimination of Flange Joints on High-Pressure High-Temperature Piping and Valves

By ERIC R. SEABLOOM,
Research welding engineer, Crane Co., Chicago, Ill.

Fusion welded piping has been used for a number of years in power plants, oil refineries and numerous other industries operating at moderate, as well as relatively high pressures and temperatures. In practically all of these installations both welded and bolted flange joints are employed, as the feeling prevails that bolted flange joints are necessary to facilitate erection and dismantling of certain units, particularly valves, which require occasional servicing of the internal parts. This is true of refinery piping where frequent dismantling is necessary for removal of carbon deposits, but on the majority of other installations welded joints can be substituted for flange joints with tremendous weight reductions, substantial savings in cost, simplification of erection and elimination of all maintenance work.

During the last few years the tendency has been to constantly increase the pressures and temperatures in steam power plants in order to obtain greater thermal efficiency. The operating conditions of some existing units have now reached 1400 pounds pressure at 925° F. total steam temperature. Numerous new stations are being planned where the working pressures and temperatures will even exceed these figures to some extent, but even a slight increase in temperature aggravates the problems of flange joints. In this type of work the savings effected by welded piping are very pronounced as the sizes involved are usually quite large and flange joints become extremely heavy, costly, difficult to erect and practically impossible to maintain tight for any reasonable period of time.

Although welding has eliminated a certain amount of flange joints, including end flange connections of valves in some of the more recent power plant additions and modernizations, it is possible to gain further advantages by welding the bonnet joints of valves. This has not yet been attempted on high pressure-high temperature service, but tests now in progress indicate that arc welding, stress relieving, and, if necessary, dismantling, rescarfing and rewelding of the bonnet joints can readily be accomplished without any distortion of the valve seats. Furthermore, valve seats have recently been vastly improved in wearing, galling, erosive and corrosive properties by means of surface hardening or depositing, so that it is seldom necessary to take valves apart for replacement of seat rings and discs.

It appears that the potentialities of welded joints in the power plant field are not completely realized and, therefore, have not been adopted to the fullest extent. The reason for this hesitancy is only natural as engineers responsible for design of equipment to render reliable unfailing service always proceed with caution in adopting new ideas or

designs. The engineering field realizes that successful operation of power plant units under these extremely critical conditions depends a great deal upon the knowledge of the behavior of materials, welding and bolting at elevated temperatures and in particular upon the phenomenon known as "creep".

It is the endeavor of this article to present the problems of high pressure-high temperature piping and how improved materials, combined with arc welding, offer the real solution to these problems, particularly those of flange joints, including the bonnet joints of valves.

Creep Problems.—During recent years, numerous metallurgical investigators have made creep tests on steels at high temperatures, resulting in the conclusion that the old methods of stress analysis, based on Hooke's law of proportionality of strain and stress, cannot be applied at elevated temperatures. This is due to the fact that steel, when subjected to stress at high temperatures, continues to elongate very slowly beyond the initial elastic deformation, which occurs when load is applied. This continuous elongation called "creep" increases with stress and temperature, but the rate of elongation is not constant, it being relatively rapid at first and decreasing with time.

On certain structures, such as piping, valves and fittings, higher creep rates are permissible, providing the change in size or shape does not affect the safety or the operating characteristics. In these structures the stress is generally constant and relatively low, so that the creep

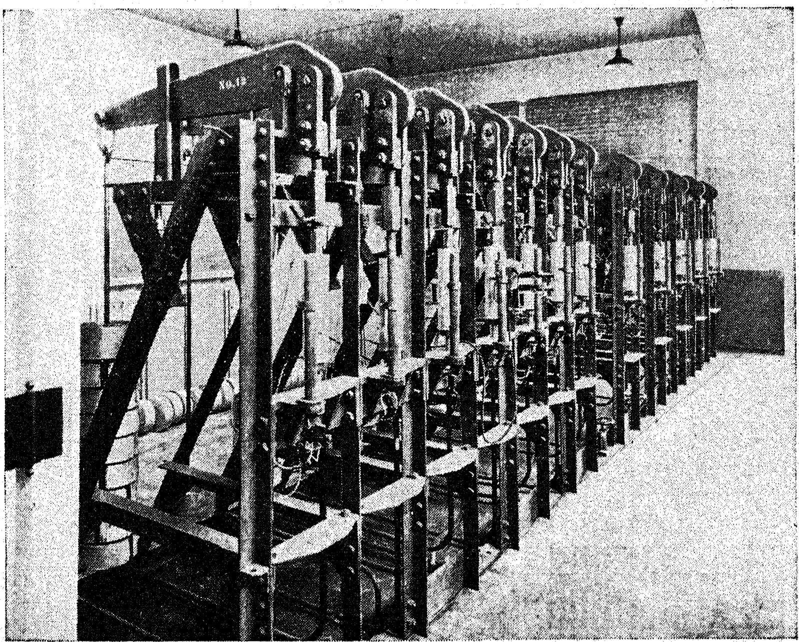


Fig. 1. Test machines for measuring creep of metals at various temperatures under constant load.

data to be applied in designing is obtained by measuring at regular intervals the deformation of test specimens heated at a constant high temperature and stressed by a constant load. Fig. 1 shows the constant temperature-load equipment for measuring creep in the Crane research laboratories.

New Alloy Steel for Welding.—Creep investigations of this character have shown that the plain carbon steels, which have been used quite generally for steam piping, including valves and fittings, are not suitable for operating temperatures above 750° F., due to their high creep rates. It has, therefore, been necessary to search for alloy steels with improved creep characteristics. There are many suitable alloy steels to choose from, but when welding of piping is to be considered it is very desirable to use a material which displays the minimum air-hardening properties. Such a material is now available in carbon-molybdenum alloy steel and while it possesses this important advantage over steels alloyed with chromium, nickel and other elements, it also offers good high temperature qualities.

Seamless drawn tubing, cast as well as forged valves and fittings, are now being made from this simple, economical alloy steel and the following comparative chemical analyses indicate that it is very similar to carbon steel, except for the addition of molybdenum. The tabulations also show the comparative physical properties of carbon and carbon-molybdenum steels at room and elevated temperatures and illustrate the excellent strength retention of the latter steel at higher temperatures.

TYPICAL CHEMICAL ANALYSES OF CARBON AND CARBON-MOLYBDENUM STEELS

	Cast Carbon Steel	Carbon Steel Pipe	Cast Carbon Moly. Steel	Carbon Moly. Steel Pipe	Carbon Moly. Forged Steel
Carbon	.33	.20	.30	.25	.25
Manganese	.75	.47	.75	.75	.55
Silicon	.35	.01	.35	.23	.25
Sulphur	.020	.023	.020	.020	.020
Phosphorus	.030	.013	.030	.020	.020
Molybdenum			.50	.50	.50

SHORT TIME HIGH TEMPERATURE TESTS ON CARBON AND CARBON-MOLYBDENUM CAST STEELS

	Carbon Steel				Carbon-Molybdenum Steel			
Temp. °F.	Tensile Strength*	Yield Point*	% Elong. in 2″	% Red. of Area	Tensile Strength*	Yield Point*	% Elong. in 2″	% Red. of Area
70	79000	44000	28.0	44.0	85000	63500	28.0	56.0
700	67500	36000	30.0	42.0	82000	50000	19.5	46.0
750	63400	35000	32.5	49.0	80000	50000	20.0	53.0
800	60000	34000	34.5	53.5	78000	49000	22.0	56.0
850	54000	32000	36.0	57.0	73000	47000	23.0	60.0
900	48000	30000	37.0	58.0	68000	44000	24.0	62.0
950	42000	27500	35.0	56.0	63000	40000	25.0	63.0
1000	37500	26000	31.0	50.0	58000	36000	26.0	63.0

*Pounds per square inch.

The short-time high-temperature data was obtained by using the equipment shown in Fig. 2 on carbon and carbon-molybdenum steels having the same carbon content. The true value of a steel for continuous high temperature service is its creep strength and at temperatures above 750° F. it is quite essential to employ a new type of stress

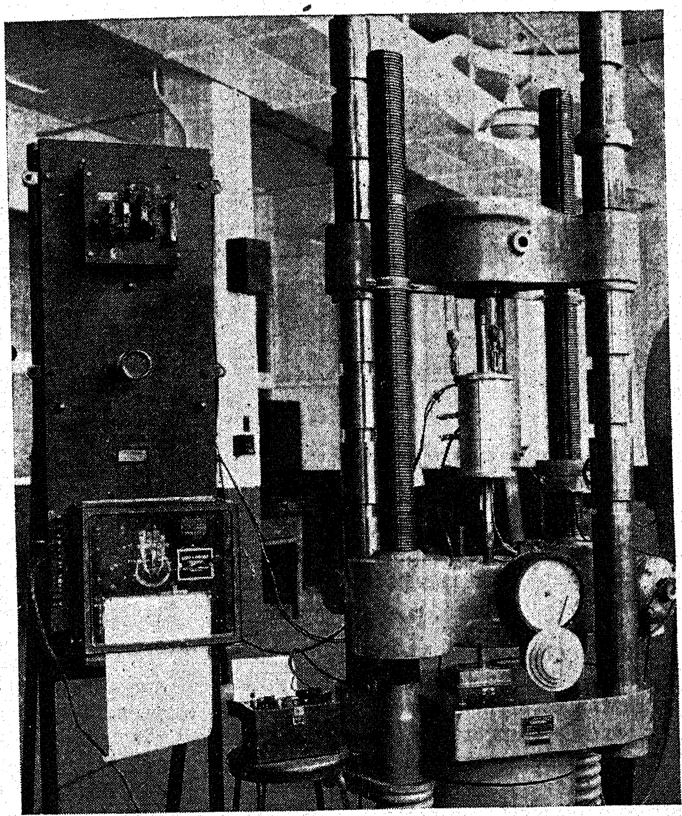


Fig. 2. Short-time high-temperature test equipment applied to 200,000-pound hydraulic tensile machine.

analysis as previously mentioned. Creep stresses are generally defined in terms of total creep per life period instead of rates of creep because the latter are not constant. Consequently, for design purposes, stresses yielding creep of 0.1 per cent for 10,000 hours or 1 per cent for 10,000 hours are used, depending upon the permanent deformation that is permissible or desirable in a structure during its service life.

Fig. 3 gives comparative creep strength of carbon and carbon-molybdenum steels at temperatures from 600° to 1100° F. based on 0.1 per cent and 1 per cent total creep in 10,000 hours. It will be observed from Fig. 3 that the resistance to creep of carbon-molybdenum steel over that of carbon steel is very marked and makes it possible to

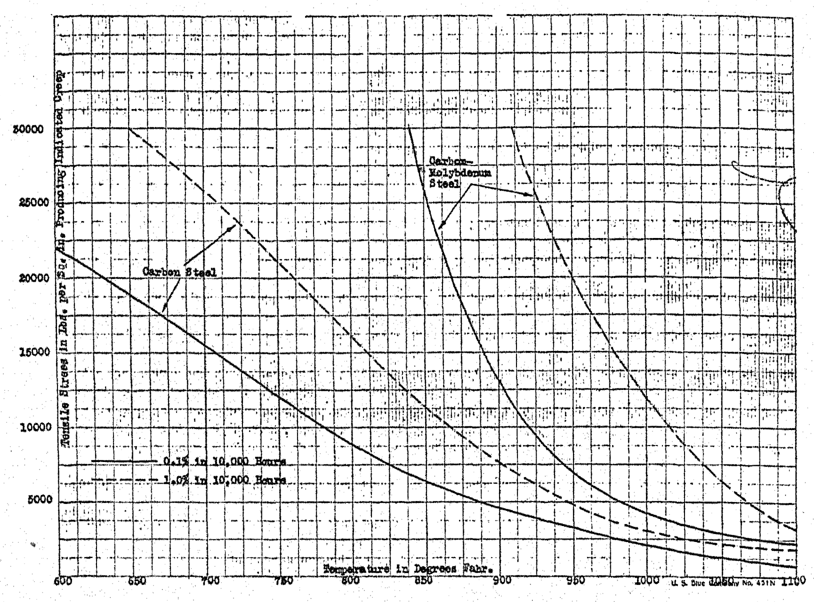


Fig. 3. Creep strengths of carbon and carbon-molybdenum cast steels.

employ approximately the same working stresses for carbon-molybdenum steel at 950° F. as those used for carbon steel at 750° F., thus making it suitable for the potential operating temperature range of power piping.

Weldability of Carbon-Molybdenum Steel.—The welding of carbon-molybdenum alloy steel compares favorably with that of carbon steel. It is desirable to preheat before welding so as to prevent cracking of the first weld deposits, which are otherwise subjected to a rapid quench. It is generally necessary to employ somewhat smaller diameter electrodes with the consequent increase in the number of beads or passes deposited, particularly on position work. Figs. 4 and 5 illustrate welding procedures for carbon-molybdenum steel, using carbon-molybdenum electrodes. These electrodes perform very satisfactorily and give excellent weld properties, as illustrated by the following representative weld test. This test weld was made in the horizontal fixed position, adhering to the procedure outlined in Fig. 5 on 14″ diameter 1¼″ wall thickness A.S.T.M. A-158 Grade P1 carbon-molybdenum steel pipe. The weld was stress relieved at 1250° F. for two hours.

PHYSICAL PROPERTIES OF CARBON-MOLYBDENUM WELD SPECIMENS

Average tensile strength	72,600 lbs. per sq. in.	Failure in pipe
Average yield point	56,900 lbs. per sq. in.	
Average free bend elongation	62%	No failure with 180° bend

FOR TYPE A WELDS

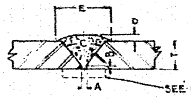
THICKNESS OF PIPE	EDGE PREPARATION FIG №	NUMBER OF PASSES	PASS №	DIAMETER OF ELECTRODES	MINIMUM ARC VOLTAGE	WELDING CURRENT AMPERES
LESS THAN $\frac{3}{16}$	1	2	1 & 2	$\frac{1}{8}$	25	100-135
$\frac{3}{16}$	1	2	1 & 2	$\frac{5}{32}$	28	125-200
$\frac{1}{4}$	1	3	1	$\frac{5}{32}$	28	125-200
$\frac{5}{16}$		3	1 & 2	$\frac{5}{32}$	28	125-200
			3	$\frac{3}{16}$	30	175-250
$\frac{3}{8}$		3	1	$\frac{5}{32}$	28	125-200
			2 & 3	$\frac{3}{16}$	30	175-250
$\frac{7}{16}$	1	4	1 & 2	$\frac{5}{32}$	28	125-200
			3 & 4	$\frac{3}{16}$	30	175-250
$\frac{1}{2}$	1	5	1 TO 3	$\frac{5}{32}$	28	125-200
			4 & 5	$\frac{3}{16}$	30	175-250
$\frac{9}{16}$		6	1 TO 3	$\frac{5}{32}$	28	125-200
			4 TO 6	$\frac{3}{16}$	30	175-250
$\frac{5}{8}$		6	1 & 2	$\frac{5}{32}$	28	125-200
			3 TO 6	$\frac{3}{16}$	30	175-250
$\frac{11}{16}$	1	7	1 TO 3	$\frac{5}{32}$	28	125-200
			4 TO 7	$\frac{3}{16}$	30	175-250
$\frac{3}{4}$	1	7	1 & 2	$\frac{5}{32}$	28	125-200
			3 TO 7	$\frac{3}{16}$	30	175-250
② $\frac{7}{8}$	2	8	1 TO 3	$\frac{5}{32}$	28	125-200
			4 TO 8	$\frac{3}{16}$	30	175-250
1	2	9	1 TO 3	$\frac{5}{32}$	28	125-200
			4 TO 9	$\frac{3}{16}$	30	175-250
$1\frac{1}{8}$	2	10	1 TO 3	$\frac{5}{32}$	28	125-200
			4 TO 10	$\frac{3}{16}$	30	175-250
$1\frac{1}{4}$	2	11	1 TO 3	$\frac{5}{32}$	28	125-200
			4 TO 11	$\frac{3}{16}$	30	175-250
$1\frac{3}{8}$	2	12	1 TO 3	$\frac{5}{32}$	28	125-200
			4 TO 12	$\frac{3}{16}$	30	175-250
$1\frac{1}{2}$	2	13	1 TO 3	$\frac{5}{32}$	28	125-200
			4 TO 13	$\frac{3}{16}$	30	175-250
$1\frac{5}{8}$	2	14	1 TO 3	$\frac{5}{32}$	28	125-200
			4 TO 14	$\frac{3}{16}$	30	175-250
$1\frac{3}{4}$	2	16	1 TO 3	$\frac{5}{32}$	28	125-200
			4 TO 16	$\frac{3}{16}$	30	175-250
$1\frac{7}{8}$	2	18	1 TO 3	$\frac{5}{32}$	28	125-200
			4 TO 18	$\frac{3}{16}$	30	175-250

PREHEAT 400°F TO 800°F BEFORE WELDING TO PREVENT CHILLING OF DEPOSITED METAL

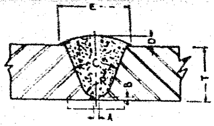
① ADDITIONAL THICKNESS IS NECESSARY IN WALL OF THE PIPE IF A GROOVE IS COUNTERBORED TO ADMIT THE BACK-UP RING

SIZE OF BACK-UP RING FOR 6 AND SMALLER PIPE SHOULD BE $\frac{1}{8}$ X $\frac{3}{4}$

SIZE OF BACK-UP RING FOR PIPE LARGER THAN 6" SHOULD BE $\frac{1}{8}$ X 1"



STANDARD STRAIGHT BEVEL



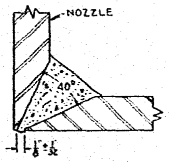
STANDARD U BEVEL

FOR TYPE A WELDS

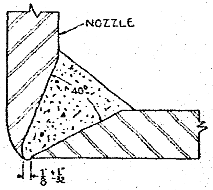
THICKNESS OF PIPE (T)	EDGE PREPARATION FIG №	A: WITH BACK-UP RING	A: WITHOUT BACK-UP RING	B	C TOTAL ANGLE	D APPROX	E-APPROX WIDTH OF WELD: WITH OR WITH OUT BACK-UP RING	R RADIUS	NUMBER OF PASSES			
LESS THAN $\frac{3}{16}$	1	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{32}$ MAX	$75°\pm5°$	$\frac{3}{32}$	$\frac{7}{16}$		2			
$\frac{3}{16}$	1	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{16}\pm\frac{1}{32}$	$75°\pm5°$	$\frac{3}{32}$	$\frac{1}{2}$		2			
$\frac{1}{4}$	1	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{16}\pm\frac{1}{32}$	$75°\pm5°$	$\frac{3}{32}$	$\frac{5}{8}$		3			
$\frac{5}{16}$	1	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{16}\pm\frac{1}{32}$	$75°\pm5°$	$\frac{1}{8}$	$\frac{3}{4}$		3			
$\frac{3}{8}$	1	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{16}\pm\frac{1}{32}$	$75°\pm5°$	$\frac{1}{8}$	$\frac{7}{8}$		3			
$\frac{7}{16}$	1	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{16}\pm\frac{1}{32}$	$75°\pm5°$	$\frac{1}{8}$	1		4			
$\frac{1}{2}$	1	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{16}\pm\frac{1}{32}$	$75°\pm5°$	$\frac{1}{8}$	$1\frac{1}{8}$		5			
$\frac{9}{16}$	1	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{16}\pm\frac{1}{32}$	$75°\pm5°$	$\frac{5}{32}$	$1\frac{1}{4}$		6			
$\frac{5}{8}$	1	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{16}\pm\frac{1}{32}$	$75°\pm5°$	$\frac{5}{32}$	$1\frac{3}{8}$		6			
$\frac{11}{16}$	1	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{16}\pm\frac{1}{32}$	$75°\pm5°$	$\frac{5}{32}$	$1\frac{1}{2}$		7			
$\frac{3}{4}$	1	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{16}\pm\frac{1}{32}$	$75°\pm5°$	$\frac{3}{16}$	$1\frac{5}{8}$	$\frac{3}{16}$	7			
② $\frac{7}{8}$	2	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{16}\pm\frac{1}{32}$	$40°\pm5°$	$\frac{3}{16}$	$1\frac{3}{8}$	$\frac{3}{16}$	8			
1	2	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{16}\pm\frac{1}{32}$	$40°\pm5°$	$\frac{3}{16}$	$1\frac{1}{2}$	$\frac{3}{16}$	9			
$1\frac{1}{8}$	2	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{16}\pm\frac{1}{32}$	$40°\pm5°$	$\frac{3}{16}$	$1\frac{5}{8}$	$\frac{3}{16}$	10			
$1\frac{1}{4}$	2	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{16}\pm\frac{1}{32}$	$40°\pm5°$	$\frac{3}{16}$	$1\frac{3}{4}$	$\frac{3}{16}$	11			
$1\frac{3}{8}$	2	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{16}\pm\frac{1}{32}$	$40°\pm5°$	$\frac{3}{16}$	$1\frac{7}{8}$	$\frac{3}{16}$	12			
$1\frac{1}{2}$	2	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{16}\pm\frac{1}{32}$	$40°\pm5°$	$\frac{3}{16}$	2	$\frac{3}{16}$	13			
$1\frac{5}{8}$	2	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{16}\pm\frac{1}{32}$	$40°\pm5°$	$\frac{3}{16}$	$2\frac{1}{8}$	$\frac{3}{16}$	14			
$1\frac{3}{4}$	2	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{16}\pm\frac{1}{32}$	$40°\pm5°$	$\frac{3}{16}$	$2\frac{1}{4}$	$\frac{3}{16}$	16			
$1\frac{7}{8}$	2	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{16}\pm\frac{1}{32}$	$40°\pm5°$	$\frac{3}{16}$	$2\frac{3}{8}$	$\frac{3}{16}$	18			

② WHEN THICKNESS IS BETWEEN $\frac{3}{4}$ & $\frac{7}{8}$, SCARF STANDARD U BEVEL

TYPE A
WELDS IN WHICH THE AXIS OF THE PIPE AT THE JOINT DOES NOT DEVIATE FROM THE HORIZONTAL BY MORE THAN 30° AND THE PIPE IS ROTATED SO THAT THE WELDING MAY ALWAYS BE DONE IN APPROXIMATELY FLAT POSITION.



SECTION THROUGH CROTCH OF NOZZLE WELD ON SECTIONS UP TO AND INCLUDING 5" ANGLE LOCATION WILL VARY WITH THICKNESS AND NOZZLE COMBINATIONS.



SECTION THROUGH CROTCH OF NOZZLE WELD ON SECTIONS $\frac{11}{16}$" TO $1\frac{1}{2}$" INCLUSIVE. ANGLE LOCATION WILL VARY WITH THICKNESS AND NOZZLE COMBINATIONS.

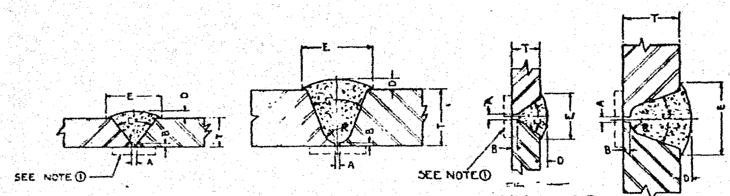
Fig. 4. Arc welding procedure for carbon-molybdenum down-hand horizontal roll welds.

THICKNESS OF PIPE	FOR TYPE B WELDS: EDGE PREPARATION FIG Nº	NUMBER OF PASSES	PASS Nº	DIAMETER OF ELECTRODE	MINIMUM ARC VOLTAGE	WELDING CURRENT AMPERES	FOR TYPE C WELDS: EDGE PREPARATION FIG Nº	NUMBER OF PASSES	PASS Nº	DIAMETER OF ELECTRODE	MINIMUM ARC VOLTAGE	WELDING CURRENT AMPERES
LESS THAN $\frac{3}{16}$	1	2	1&2	$\frac{1}{8}$	25	100-135	3	2	1&2	$\frac{1}{8}$	25	100-135
$\frac{3}{16}$	1	3	1TO3	$\frac{1}{8}$	25	100-135	3	3	1TO3	$\frac{1}{8}$	25	100-135
$\frac{1}{4}$	1	3	1	$\frac{1}{8}$	25	100-135	3	4	1TO4	$\frac{1}{8}$	25	100-135
			2&3	$\frac{5}{32}$	28	125-200						
$\frac{5}{16}$	1	4	1&2	$\frac{1}{8}$	25	100-135	3	4	1&2	$\frac{1}{8}$	25	100-135
			3&4	$\frac{5}{32}$	28	125-200			3&4	$\frac{5}{32}$	28	125-200
$\frac{3}{8}$	1	4	1	$\frac{1}{8}$	25	100-135	3	5	1&2	$\frac{1}{8}$	25	100-135
			2TO4	$\frac{5}{32}$	28	125-200			3TO5	$\frac{5}{32}$	28	125-200
$\frac{7}{16}$	1	5	1	$\frac{1}{8}$	25	100-135	3	6	1&2	$\frac{1}{8}$	25	100-135
			2TO5	$\frac{5}{32}$	28	125-200			3TO6	$\frac{5}{32}$	28	125-200
$\frac{1}{2}$	1	6	1	$\frac{1}{8}$	25	100-135	3	7	1&2	$\frac{1}{8}$	25	100-135
			2TO6	$\frac{5}{32}$	28	125-200			3TO7	$\frac{5}{32}$	28	125-200
$\frac{9}{16}$	1	7	1&2	$\frac{1}{8}$	25	100-135	3	8	1&2	$\frac{1}{8}$	25	100-135
			3TO7	$\frac{5}{32}$	28	125-200			3TO8	$\frac{5}{32}$	28	125-200
$\frac{5}{8}$	1	8	1&2	$\frac{1}{8}$	25	100-135	3	9	1&2	$\frac{1}{8}$	25	100-135
			3TO8	$\frac{5}{32}$	28	125-200			3TO9	$\frac{5}{32}$	28	125-200
$\frac{11}{16}$	1	9	1&2	$\frac{1}{8}$	25	100-135	3	11	1&2	$\frac{1}{8}$	25	100-135
			3TO9	$\frac{5}{32}$	28	125-200			3TO11	$\frac{5}{32}$	28	125-200
$\frac{3}{4}$	1	10	1&2	$\frac{1}{8}$	25	100-135	3	3	1&2	$\frac{1}{8}$	25	100-135
			3TO10	$\frac{5}{32}$	28	125-200			3TO13	$\frac{5}{32}$	28	125-200
$\frac{7}{8}$	2	11	1&2	$\frac{1}{8}$	25	100-135	4	15	1&2	$\frac{1}{8}$	25	100-135
			3TO11	$\frac{5}{32}$	28	125-200			3TO15	$\frac{5}{32}$	28	125-200
1	2	13	1&2	$\frac{1}{8}$	25	100-135	4	17	1&2	$\frac{1}{8}$	25	100-135
			3TO13	$\frac{5}{32}$	28	125-200			3TO17	$\frac{5}{32}$	28	125-200
$1\frac{1}{8}$	2	15	1&2	$\frac{1}{8}$	25	100-135	4	19	1&2	$\frac{1}{8}$	25	100-135
			3TO15	$\frac{5}{32}$	28	125-200			3TO19	$\frac{5}{32}$	28	125-200
$1\frac{1}{4}$	2	17	1&2	$\frac{1}{8}$	25	100-135	4	21	1&2	$\frac{1}{8}$	25	100-135
			3TO17	$\frac{5}{32}$	28	125-200			3TO21	$\frac{5}{32}$	28	125-200
$1\frac{3}{8}$	2	19	1&2	$\frac{1}{8}$	25	100-135	4	24	1&2	$\frac{1}{8}$	25	100-135
			3TO19	$\frac{5}{32}$	28	125-200			3TO24	$\frac{5}{32}$	28	125-200
$1\frac{1}{2}$	2	21	1&2	$\frac{1}{8}$	25	100-135	4	27	1&2	$\frac{1}{8}$	25	100-135
			3TO21	$\frac{5}{32}$	28	125-200			3TO27	$\frac{5}{32}$	28	125-200
$1\frac{5}{8}$	2	23	1&2	$\frac{1}{8}$	25	100-135	4	30	1&2	$\frac{1}{8}$	25	100-135
			3TO23	$\frac{5}{32}$	28	125-200			3TO27	$\frac{5}{32}$	28	125-200
$1\frac{3}{4}$	2	25	1&2	$\frac{1}{8}$	25	100-135	4	34	1&2	$\frac{1}{8}$	25	100-135
			3TO25	$\frac{5}{32}$	28	125-200			3TO34	$\frac{5}{32}$	28	125-200
$1\frac{7}{8}$	2	27	1&2	$\frac{1}{8}$	25	100-135	4	38	1&2	$\frac{1}{8}$	25	100-135
			3TO27	$\frac{5}{32}$	28	125-200			3TO38	$\frac{5}{32}$	28	125-200

PREHEAT, 400°F TO 800°F BEFORE WELDING TO PREVENT CHILLING OF DEPOSITED METAL.

① ADDITIONAL THICKNESS IS NECESSARY IN THE WALL OF THE PIPE IF A GROOVE IS COUNTERBORED TO ADMIT THE BACK-UP RING.

SIZE OF BACK-UP RING FOR PIPE 6" AND SMALLER SHOULD BE $\frac{1}{8}$ x $\frac{3}{4}$".
SIZE OF BACK-UP RING FOR PIPE LARGER THAN 6" SHOULD BE $\frac{1}{8}$ x 1".



STANDARD STRAIGHT BEVEL — STANDARD U BEVEL — STANDARD STRAIGHT BEVEL — STANDARD U BEVEL

FOR TYPE "B" WELDS

THICKNESS OF PIPE (T)	EDGE PREPARATION FIG Nº	A: WITH BACK-UP RING	A: WITHOUT BACK-UP RING	B	C TOTAL ANGLE	D APPROX	E APPROX. WIDTH OF WELD WITH OR WITHOUT BACK-UP RING	R RADIUS
LESS THAN $\frac{3}{16}$	1 OR 3	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{32}$ MAX	75°±5°	$\frac{3}{32}$	$\frac{1}{4}$	
$\frac{3}{16}$	1 OR 3	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{16}\pm\frac{1}{32}$	75°±5°	$\frac{3}{32}$	$\frac{1}{2}$	
$\frac{1}{4}$	1 OR 3	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{16}\pm\frac{1}{32}$	75°±5°	$\frac{3}{32}$	$\frac{5}{8}$	
$\frac{5}{16}$	1 OR 3	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{16}\pm\frac{1}{32}$	75°±5°	$\frac{1}{8}$	$\frac{3}{4}$	
$\frac{3}{8}$	1 OR 3	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{16}\pm\frac{1}{32}$	75°±5°	$\frac{1}{8}$	$\frac{7}{8}$	
$\frac{7}{16}$	1 OR 3	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{16}\pm\frac{1}{32}$	75°±5°	$\frac{1}{8}$	1	
$\frac{1}{2}$	1 OR 3	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{16}\pm\frac{1}{32}$	75°±5°	$\frac{1}{8}$	$1\frac{1}{8}$	
$\frac{9}{16}$	1 OR 3	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{16}\pm\frac{1}{32}$	75°±5°	$\frac{3}{32}$	$1\frac{1}{4}$	
$\frac{5}{8}$	1 OR 3	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{16}\pm\frac{1}{32}$	75°±5°	$\frac{5}{32}$	$1\frac{3}{8}$	
$\frac{11}{16}$	1 OR 3	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{16}\pm\frac{1}{32}$	75°±5°	$\frac{3}{32}$	$1\frac{1}{2}$	
$\frac{3}{4}$	1 OR 3	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{16}\pm\frac{1}{32}$	75°±5°	$\frac{3}{16}$	$1\frac{5}{8}$	
② $\frac{7}{8}$	2 OR 4	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{16}\pm\frac{1}{32}$	40°±5°	$\frac{3}{16}$	$1\frac{3}{8}$	$\frac{3}{16}$
1	2 OR 4	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{16}\pm\frac{1}{32}$	40°±5°	$\frac{3}{16}$	$1\frac{1}{2}$	$\frac{3}{16}$
$1\frac{1}{8}$	2 OR 4	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{16}\pm\frac{1}{32}$	40°±5°	$\frac{3}{16}$	$1\frac{5}{8}$	$\frac{3}{16}$
$1\frac{1}{4}$	2 OR 4	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{16}\pm\frac{1}{32}$	40°±5°	$\frac{3}{16}$	$1\frac{3}{4}$	$\frac{3}{16}$
$1\frac{3}{8}$	2 OR 4	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{16}\pm\frac{1}{32}$	40°±5°	$\frac{3}{16}$	$1\frac{7}{8}$	$\frac{3}{16}$
$1\frac{1}{2}$	2 OR 4	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{16}\pm\frac{1}{32}$	40°±5°	$\frac{3}{16}$	2	$\frac{3}{16}$
$1\frac{5}{8}$	2 OR 4	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{16}\pm\frac{1}{32}$	40°±5°	$\frac{3}{16}$	$2\frac{1}{8}$	$\frac{3}{16}$
$1\frac{3}{4}$	2 OR 4	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{16}\pm\frac{1}{32}$	40°±5°	$\frac{3}{16}$	$2\frac{1}{4}$	$\frac{3}{16}$
$1\frac{7}{8}$	2 OR 4	$\frac{1}{8}-\frac{3}{16}$	$\frac{1}{16}\pm\frac{1}{32}$	$\frac{1}{16}\pm\frac{1}{32}$	40°±5°	$\frac{3}{16}$	$2\frac{3}{8}$	$\frac{3}{16}$

② WHEN THICKNESS IS BETWEEN $\frac{3}{4}$" & $\frac{7}{8}$", SCARF STANDARD U BEVEL

FOR TYPE "C" WELDS STANDARD U BEVEL

TYPE B-WELDS IN WHICH THE AXIS OF THE PIPE AT THE JOINT DOES NOT DEVIATE FROM THE HORIZONTAL BY MORE THAN 30° AND THE PIPE IS NOT ROTATED SO THAT THE WELDING MUST BE DONE IN A COMBINATION OF THE FLAT, VERTICAL, AND OVERHEAD POSITION

TYPE C-WELDS IN WHICH THE ANGLE BETWEEN THE AXIS OF THE PIPE AT THE JOINT AND A HORIZONTAL PLANE EXCEEDS 30° SO THAT THE WELDING IS DONE IN A COMBINATION OF THE HORIZONTAL AND OVERHEAD POSITION

Fig. 5. Arc welding procedure for carbon-molybdenum horizontal and vertical fixed position welds.

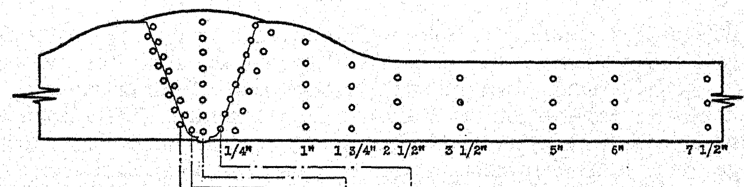
Average back bend elongation	44%	Complete fusion at bottom — No failure with 180° bend
Side break test specimens		Bend 180° without failure indicating good side wall fusion in groove
Nick break test specimens		Free from gas pockets and slag inclusions. Silky and fine grain structure
Charpy impact value at 70° F.	29.5 ft. lbs.	

CHEMICAL ANALYSIS OF DEPOSITED WELD METAL

Carbon	Manganese	Silicon	Sulphur	Phosphorous	Molybdenum
.12	.63	.32	.010	.025	.59

Similar results are also obtained on welds made on carbon-molybdenum cast steel.

Air-Hardening Properties.—Many alloy steels with good high-temperature properties have a tendency to harden to a marked degree after being subjected to the welding temperature and under some service conditions may make their use hazardous. Stress relieving, if performed at a sufficiently high temperature, reduces the hardness and brittleness, but this cannot always be accomplished immediately or conveniently. As stated before, one of the desirable qualities of carbon-molybdenum steel is its very moderate air hardening properties. Many designing engineers require that this steel also be stress relieved after welding and while this is considered good practice on important installations, it is not entirely essential, especially on small sizes of piping, such as drain lines and by-passes. Fig. 6 gives hardness data in welds made on carbon-molybdenum steel tubing in both the "as welded" and "stress relieved" conditions. Welds made on carbon-molybdenum cast steel yield approximately similar results. It can thus be seen that arc welding of carbon-molybdenum alloy steel pipe and castings for use at high temperatures and pressures presents no problems. Furthermore, distinct advantages can be gained over flange joints, as will be brought out later, particularly in reference to creep, since the stresses on welded joints are practically the same as those on the piping, and



	1/8 OUTSIDE FUSION ZONE	1/8 INSIDE FUSION ZONE	CENTER-LINE	FUSION ZONE	DISTANCE FROM FUSION ZONE							
					1/4	1	1 3/4	2 1/2	3 1/2	5	6	7 1/2
As Welded	185	232	229	219	159	149	143	148	143	141	134	128
Stress Relieved at 1210° F.	152	176	178	161	142	133	134	138	138	133	128	122

Fig. 6. Brinnel hardness of carbon-molybdenum weld and tubing, 14 in. O.D., upset from 1½ in. to 1⅞ in., normalized after upsetting from 1650 degrees Fahr.

these are relatively low compared to the stresses imposed upon flange joint bolting.

Flange Joints and Their Problems.—Flanges for use on higher pressures necessarily are very large and extremely heavy, particularly on the 1500-pound class of service. Naturally they are expensive because of their weight and the machine work required in facing, turning, boring and drilling. Table I gives the principal dimensions of American Standards Association 1500-pound steel companion flanges, including size of bolts and weights.

TABLE I—PRINCIPAL DIMENSIONS A.S.A. 1500-LB. STEEL COMPANION FLANGES

Nominal Pipe Size	Outside Diameter of Flange	Thickness of Flange	Diameter of Hub	Length Through Hub	No. of Bolts	Size of Bolts	Weight of Flange
2	8½	1½	4⅛	2¼	8	⅞	23
2½	9⅝	1⅝	4⅞	2½	8	1	32
3	10½	1⅞	5¼	2⅞	8	1⅛	42
4	12¼	2⅛	6⅜	$3\frac{9}{16}$	8	1¼	63
5	14¾	2⅞	7¾	4⅛	8	1½	123
6	15½	3¼	9	$4\frac{11}{16}$	12	1⅜	137
8	19	3⅝	11½	5⅝	12	1⅝	216
10	23	4¼	14½	7	12	1⅞	355
12	26½	4⅞	17¾	8⅝	16	2	525
14 O.D.	29½	5¼	19½	9½	16	2¼	720
16 O.D.	32½	5¾	21¾	10¼	16	2½	930
18 O.D.	36	6⅜	23½	10⅞	16	2¾	1240
20 O.D.	38¾	7	25¼	11½	16	3	1512
24 O.D.	46	8	39	13	16	3½	2400

The tremendous weights that are required in flanges and their bolting members for joining of piping, valves and fittings are completely eliminated when welded joints are employed. Since there are virtually hundreds of joints of various sizes in a power plant unit, the weight reduction is very substantial not only in the joints themselves, but also in hangers and structural supports.

Difficulties in Pulling up Bolts.—One of the most difficult problems encountered with the larger sizes of 1500-pound flanges is the pulling up of the bolts when assembling. Although the bolting of American Standards Association flanges is designed on a basis of 7,000 pounds stress per square inch, it has been found by tests and experience that flange joints leak when this amount of bolt stress is applied and the leakage will continue in numerous cases even when the bolts are stressed up to 15,000 pounds per square inch, especially when flat gaskets are used. This is due to the fact that most gaskets only give efficiencies or performance factors of .40 to .75. Consequently, in order to assure tight joints it is necessary to stress the bolting to at least 30,000 pounds per square inch, which is now common practice. On the

smaller sizes of flanges, where the bolts are relatively small in diameter, this offers no problem as stresses beyond 60,000 pounds are readily attained without much turning effort on the wrenches. In fact, there is a danger of over-stressing unless caution is observed. As flange and bolt sizes increase the torque loads required to obtain the minimum stress of 30,000 pounds mount tremendously and present a real difficulty to valve manufacturers, piping erectors and maintenance departments of power plants. Table II gives the turning efforts necessary on nuts of various diameters of bolts to obtain certain fiber stresses. This data was obtained on bolts and nuts with well lubricated threads and bearing surfaces and represents years of experience with flange-joint bolting in the Crane research laboratories.

TABLE II—TURNING EFFORTS REQUIRED TO OBTAIN VARIOUS BOLT STRESSES

				STRESS					
				30,000 Lb. per Sq. In.		45,000 Lb. per Sq. In.		60,000 Lb. per Sq. In.	
Nom. Dia. of Bolt, In.	No. of Th'ds. per In.	Dia. at Root of Thrd.	Area at Root of Thrd.	Torque Ft.-Lb.	Compression Lb.	Torque Ft.-Lb.	Compression Lb.	Torque Ft.-Lb.	Compression Lb.
1/4	20	0.185	0.027	4	810	6	1215	8	1620
5/16	18	0.240	0.045	8	1350	12	2025	16	2700
3/8	16	0.294	0.068	12	2040	18	3060	24	4080
7/16	14	0.345	0.093	20	2790	30	4185	40	5580
1/2	13	0.400	0.126	30	3780	45	5670	60	7560
9/16	12	0.454	0.162	45	4860	68	7290	90	9720
5/8	11	0.507	0.202	60	6060	90	9090	120	12120
3/4	10	0.620	0.302	100	9060	150	13590	200	18120
7/8	9	0.731	0.419	160	12570	240	18855	320	25140
1	8	0.838	0.551	245	16530	368	24795	490	33060
1 1/8	8	0.963	0.728	355	21840	533	32760	710	43680
1 1/4	8	1.088	0.929	500	27870	750	41805	1000	55740
1 3/8	8	1.213	1.155	680	34650	1020	51975	1360	69300
1 1/2	8	1.338	1.405	800	42150	1200	63225	1600	84300
1 5/8	8	1.463	1.680	1100	50400	1650	75600	2200	100800
1 3/4	8	1.588	1.980	1500	59400	2250	89100	3000	118800
1 7/8	8	1.713	2.304	2000	69120	3000	103680	4000	138240
2	8	1.838	2.652	2200	79560	3300	119340	4400	159120
2 1/4	8	2.088	3.423	3180	102690	4770	154035	6360	205380
2 1/2	8	2.338	4.292	4400	128760	6600	193140	8800	257520
2 3/4	8	2.588	5.259	5920	157770	8880	236655	11840	315540
3	8	2.838	6.324	7720	189720	11580	284580	15440	379440

On bolt sizes 1 7/8" diameter and larger the torque required to obtain a stress of 30,000 pounds per square inch is beyond the load that ordinary carbon steel box or socket wrenches can safely withstand. Although alloy steel wrenches are available, which offer greater

strength, occasional failures are experienced with these when they are necessarily abused, as additional leverage, obtained by means of a long pipe slipped over the end of the wrench, has to be resorted to in order to build up the proper load. Wrench failure often results in injury to the men pulling on the lever. Frequently, it is impossible to employ long levers because of cramped quarters or precarious locations of the joints.

Heavy-duty alloy steel box wrenches with striking pads at the ends have appeared on the market and by means of a sledge hammer or an air hammer, such as is used in driving rivets, it is possible to obtain quite high torque loads, without any danger of personal injury when wrench failure occurs. Based on our observations, however, it appears that the maximum torque that can be attained by this method is about 2500 foot pounds, which is not sufficient to pull up a 2¼″ diameter bolt. Furthermore, it is necessary to measure the elongation of the bolts in order to determine the stress applied, which is rather time-consuming.

On bolts 3″ and 2¾″, and possibly 2½″ in diameter, there are no suitable wrenches available, nor levers strong enough to resist bending in the lengths required to properly pull up these sizes. Consequently it is essential that a different means of applying stress be resorted to. This is known as the thermal-expansion method and consists, in general, of heating the bolts to produce thermal elongation, pulling the nuts down against the flanges with a standard wrench, allowing the bolts to cool and contract in this position, thereby creating bolt tension. The heating is done by either electrical elements or by an oxy-acetylene flame through longitudinally drilled holes in the bolts. In determining the stresses being applied to the bolts, their elongation is measured by means of a micrometer caliper or a dial indicator mounted on a special frame.

It is necessary to heat the bolts sufficiently to produce about three times the desired elongation so as to compensate for the springing of the flanges, which are generally two to four times more flexible than the bolts. Furthermore, in order to produce equal stressing of all the bolts it is essential to repeat the heating, pulling and measuring procedure several times, making it extremely tedious.

A flange joint of 20″, 1500-pound lap type, was tested with various styles of gaskets in the Crane research laboratories to obtain intimate knowledge of the problems encountered with large size high pressure bolted joints. The flanges were 38¾″ in diameter, 7″ thick and weighed 2520 pounds. The studs were 3″ in diameter, 26″ long and weighed 784 pounds, while the nuts contributed a weight of 336 pounds, making a total of 3640 pounds. It required approximately four days for a crew of six men to complete each assembly, the stressing of the bolts by the thermal-expansion method being very time-consuming. All of this weight, and a substantial reduction in man hours spent in assembling, could be eliminated by arc welding.

Creep Problems with Bolting.—Practically all piping, valves, flanges and bolting in a power plant are completely covered with insulation to reduce heat losses. Insulating flanges and bolting has a very bad

effect on the bolts as these are maintained at a higher temperature, causing a more rapid creep than would be encountered if the bolting and flanges were left uncovered. However, since flanges contribute considerable heat radiation in the uncovered condition, due to their large projected areas, it is essential that the joints be thoroughly insulated in order to provide high terminal efficiency. Welded joints are more readily covered because the insulating material may be continuous and it is not necessary to build up the insulation as is the case with flange joints. Consequently, economies are effected in the material itself and its application with resultant increased efficiencies.

As stated previously, creep increases with stress and temperature. Since bolt stresses in flanges are extremely high in order to assure tight joints, and since the bolt temperatures approach those of the operating steam temperatures due to insulation, high creep rates are produced, causing rapid loss of stress, which results in leaky joints after a comparatively short elapse of time. When creep occurs in bolting, elastic strain with a definite stress equivalent is transformed into creep strain equal to a permanent deformation, representing a loss of stress or load. This type of creep has been termed "relaxation" and as constant load creep data is not a reliable index to the relaxation character of bolting steels in flange joints a new creep testing technique has been developed.

In order to conduct proper tests on relaxation of bolting steels, it is essential to know the temperatures that the bolts are exposed to in a well insulated flange joint. An investigation of this character was made a few years ago by the Crane research laboratories on a 10″-1500 pound fabricated flanged fitting, ascertaining the differences in temperature between the steam, pipe walls, flanges and bolting at various operating temperatures under insulated conditions. This fitting was tested at 1500 pounds pressure with temperatures ranging from 650° F. to 1200° F. by heating water contained within the fitting by means of electrical heaters located in the blind flanges. The control of pressure and temperatures, as well as measurement of temperature differences of the component parts, was accomplished. The results of the tests are plotted in Fig. 7. The same equipment was also used in determining relaxation creep values of bolting steels under conditions approaching actual installations prior to the development of the special creep machine. The test results obtained on both types of apparatus check very closely, but the new equipment is much simpler to use, less cumbersome and more economical to operate.

It will be observed from Fig. 7 that at a steam temperature of 950° F., which the operating temperatures are rapidly approaching in power plants, the bolt temperature is approximately 850° F. In a flange joint under this operating condition, using alloy steel bolts of an analysis that has been commonly employed during recent years and stressed to 30,000 pounds per square inch, which is essential to assure tightness, the stress would drop to 15,000 pounds, resulting in a leaky joint in the short span of approximately 1500 hours or 9 weeks. It would then be necessary to restress the bolting by pulling up the nuts, which procedure is costly, especially if the bolts are large in diameter, as explained previously. Leakage would again occur after 4000 hours or 24 weeks, as illustrated by curves marked Steel "A" in Fig. 8. The relaxation is less

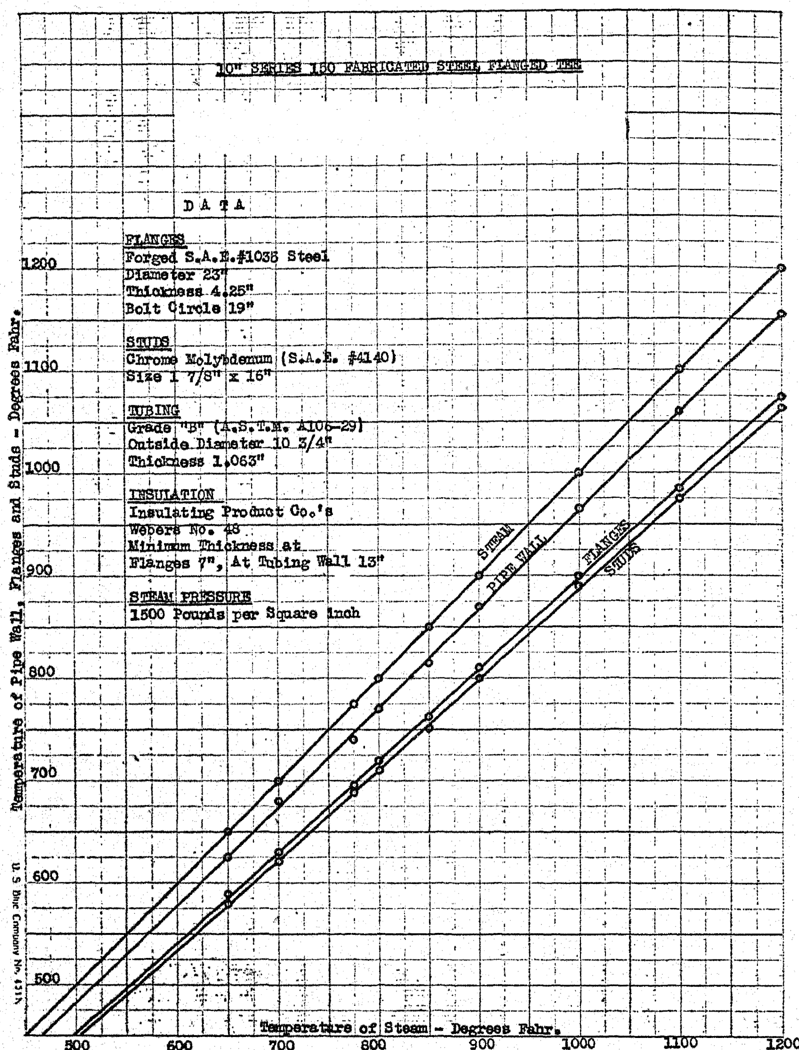


Fig. 7. Temperature difference between steam, pipe wall flanges and studs at various steam temperatures.

upon second and subsequent loadings, having increased its creep resistance by virtue of creep deformation and work hardening.

An improved alloy bolting steel has recently been introduced by Crane Co., with superior creep characteristics accomplished primarily by special heat treatment. Curve marked Steel "B" in Fig. 8 represents this new steel and its primary creep is much less than Steel "A", accounting for its smaller initial relaxation. However, even with this bolting steel it will be necessary to pull up the nuts after approximately 35,000 hours or 4 years.

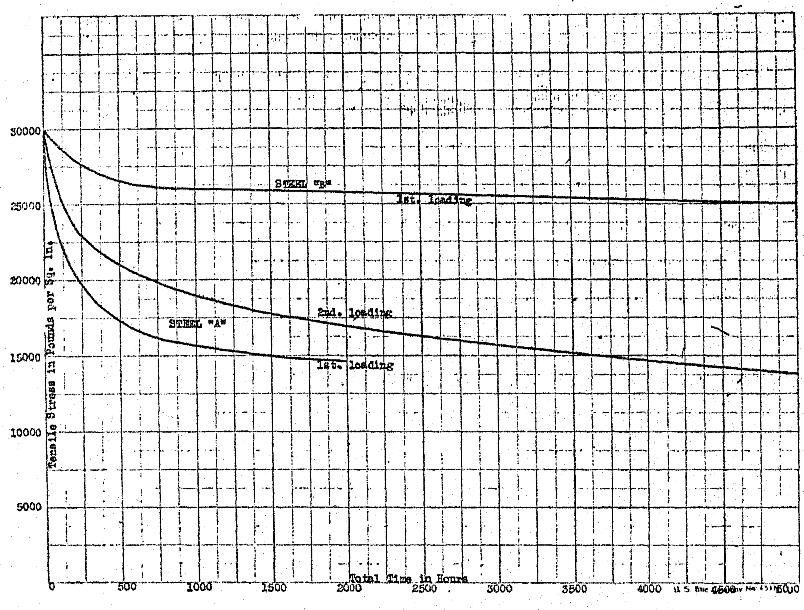


Fig. 8. Typical relaxation test curves.

Flange joints often leak from causes other than creep of bolts, especially during warming up periods when great temperature differences are encountered, sometimes caused by slugs of water being carried through the piping, resulting in unequal expansion and contraction. Welded joints, if properly designed and made, are not affected by creep to any greater extent than the piping itself; consequently, they will not require any maintenance work during the life period of the piping installation, which, generally speaking, is at least 20 years.

Welding of Valves.—Welded joints, including the welding of valves into piping, have been resorted to in some of the most recent power plant additions in an endeavor to overcome the obstacles that flange joints present. However, in these installations, the bolted flange bonnet joints have been retained on the valves and these are subject to the troubles outlined in practically the same degree as the regular American Standards Association pipe flanges since they are designed on a somewhat similar basis.

It is the purpose of this paper to propose that all bolted flanges, including those of the bonnet joints of high-pressure high-temperature valves, particularly the 1500 pound class, be eliminated by arc welding, thereby banishing the bolting and creep problems. This can readily be accomplished as a number of valve manufacturers employ carbon-molybdenum alloy steel on the higher pressure classes of valves, which material does not present any welding difficulties.

The temperature rise at the valve seats, which are the vital parts of a valve mechanism, never approaches the operating temperature when

arc welding the bonnet joint or the body end joints, providing, of course, that the preheating temperature is not excessive. Consequently, seat distortion is not likely to occur and in our experience to date has never been encountered.

Stress relieving of the welded bonnet and body end joints by means of local induction or resistance type of furnace equipment at 1200° F. does not distort the valve seats as the conducted heat is quite uniform and relatively low immediately outside of the heating collar or furnace. This is indicated by curve plotted in Fig. 9.

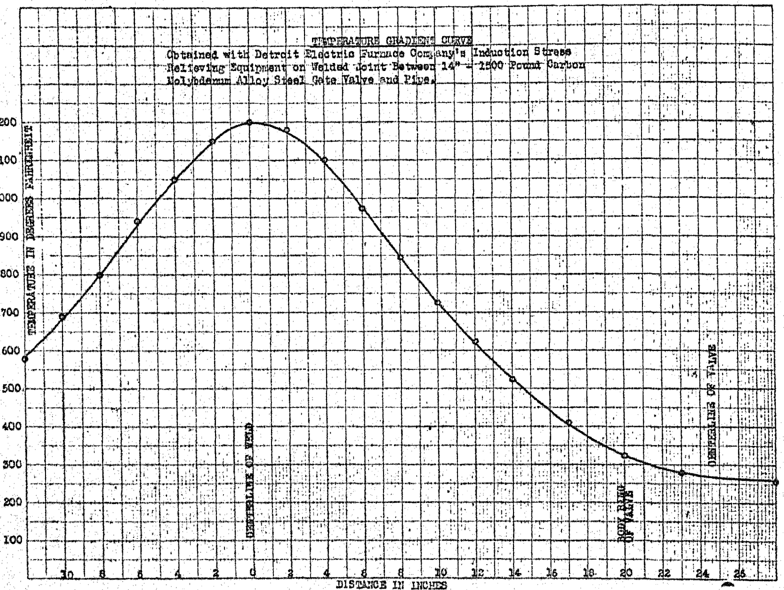


Fig. 9. Temperature gradient curve.

By introducing a rather heavy and wide back-up ring in the bonnet joint, it is possible to maintain perfect alignment of the bonnet and body while welding as this is quite essential if the internal valve mechanism is to function properly. Another advantage of the back-up ring is that if the occasion ever arises where the welded bonnet joint has to be cut open for removal and replacement of damaged valve seats, the weld and the back-up ring can be severed by an oxy-acetylene cutting flame, the bonnet and body rescarfed, a new back-up ring installed, the joint rewelded and the alignment re-established. This would be a very rare occurrence as valve seating surfaces have recently been vastly improved in resistance to galling, erosion and corrosion at elevated temperatures through the use of special alloy steels, which are deposited by means of welding.

Occasionally it is necessary to clean out the valves shortly after installation in a piping system, as sometimes an accumulation of foreign particles lodge at the bottom of the bodies preventing complete closing

of the discs. On flanged valves this is accomplished by removing the bolted bonnet joint, but this would be a rather costly procedure on an all-welded valve. A clean out opening can, however, be provided at the bottom of the valve bodies similar to a hand hole inspection cover as is used on pressure vessels to overcome this difficulty. The cover, since pressure tends to hold it tight against the internal gasket, would not be subject to the problems accompanying creep.

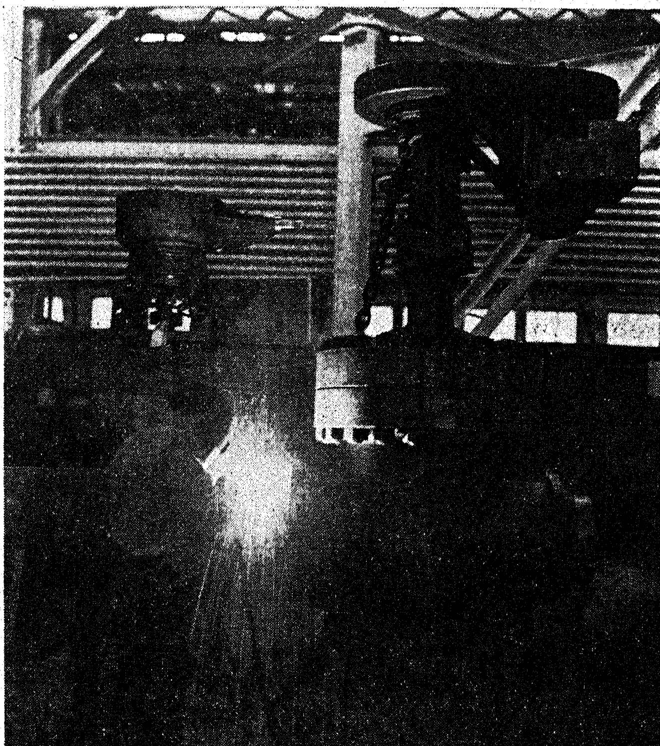


Fig. 10. Arc welding a 14-inch, 1500-pound gate valve into header. Note size of bonnet flange.

Weight Reduction by Welding.—One of the outstanding features that welding of end and bonnet connections of valves really accomplishes is a very substantial reduction in weight, brought about by the elimination of companion flanges, integral end flanges, bonnet flanges, stud-bolts and nuts, which are necessary in making the mechanical connections. Fig. 10 illustrates very emphatically the size of the bonnet flanges on a 14"-1500 pound valve being welded into a pipe header. These flanges with their studs and nuts contributed a weight of 1396 pounds, which could be removed by arc welding. Had this valve been of the flanged-end type, the total weight to complete the assembly into a pipe line would have been 10589 pounds. However, if

an all-welded valve were used the weight would only amount to 5611 pounds or a reduction of 4978 pounds, thus effecting a 47 per cent weight saving. The above weights are based on the fact that a flanged valve in addition to the bonnet flanges and their bolting also requires a pair of companion flanges, two sets of bolt studs and nuts in order to connect it to the pipe line. This is illustrated by Fig. 11, which also shows relative cross sections in proportion between flanged and welded valves.

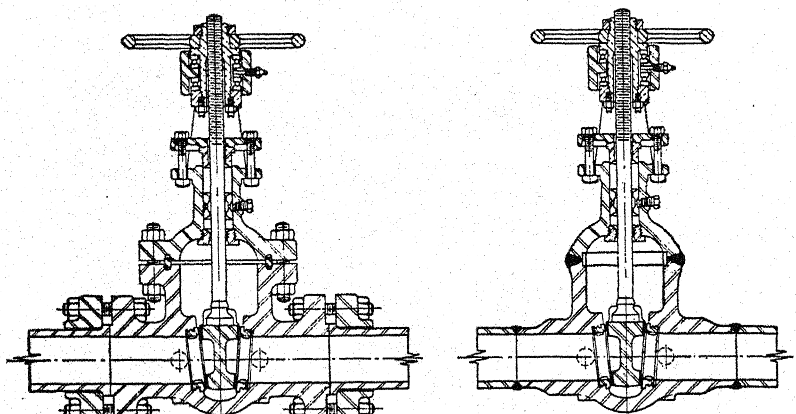


Fig. 11. Typical cross sections of 1500-pound gate valves, comparing flanged and welded construction.

In Table III are tabulated the weights of flanged and welded valves, companion flanges, integral flanges, studs, nuts and the combined weights comprising various assemblies. It will be observed from this table that when welded valves are employed an average weight reduction of approximately 50 per cent is obtained on 1500-pound valves ranging in size from 4″ to 14″. Comparative savings could also be affected on smaller and larger sizes as well as on the other pressure classes of valves, namely, 300, 400, 600, and 900 pound.

TABLE III—WEIGHTS OF FLANGED AND WELDED VALVES, COMPANION FLANGES, INTEGRAL FLANGES, STUDS, NUTS AND COMBINED WEIGHTS

Size	4	5	6	8	10	12	14
Weight of One Pair Lap Companion Flanges	126	246	274	432	710	1050	1440
Weight of End Flange Studs	44	78	104	166	258	440	614
Weight of End Flange Stud Nuts	24	42	50	80	114	196	278
Weight of Flanged Valve	615	1020	1370	2550	4290	6077	8257
Combined Weight of Flanges, Studs, Nuts and Valve	809	1386	1798	3228	5372	7763	10589

Weight of Integral End Flanges of Valve........	102	192	226	370	628	890	1250
Weight of Valve With Welding Ends............	513	828	1144	2180	3662	5187	7007
Weight of Valve Bonnet Flanges..................	94	156	212	316	496	700	1010
Weight of Bonnet Studs	30	45	51	90	139	194	263
Weight of Bonnet Stud Nuts	18	25	32	53	76	96	123
Weight of All Welded Valve	371	602	849	1721	2951	4197	5611
Weight Reduction of Welded Valve Over Flanged Valve............	438	784	949	1507	2421	3576	4978
Percentage of Weight Reduction	**54**	**57**	**53**	**47**	**45**	**46**	**47**

Cost Savings.—The cost of welding the bonnet and end flange connections of valves no doubt would be equal to the expenditure necessary to pull up the bolting on these joints in most cases. The reason for this is quite obvious, as wage scales for welding operators is generally higher than shop assembly men and about equivalent to steamfitters and their helpers. Although, it would require more men and most likely more man hours to pull up some of the flange joints, the investment in the welding generators, qualification tests of welders, which amount to approximately $800.00 per man for carbon-molybdenum steel and the insurance inspection at $20.00 per day would offset any savings that could otherwise be accomplished by welding. However, the savings effected by changing to welded construction would be derived by the discarding of the integral steel bonnet and end flanges, the companion flanges, studs and nuts. Table IV shows these savings in tabular form. The prices on lap companion flanges are based on the net figures established by the Power Piping Society, the prices on studs and nuts are taken from Crane Co.'s No. 1 discount sheet and the savings on steel in the integral flanges are very conservatively figured. The savings afforded by the elimination of integral cast flanges would not be effective immediately unless the demand for welded valves increases materially as at the present time they are made up as specials only and production equipment and methods are not yet employed.

The use of all-welded piping and valves is bound to grow, especially on high temperature service if the problems outlined in this article are to be avoided.

TABLE IV—COST OF FLANGED AND WELDED VALVES, COMPANION FLANGES, STUDS, NUTS AND POTENTIAL SAVINGS OBTAINED BY WELDING

Size	4	5	6	8	10	12	14
Cost of One Pair of Companion Flanges Including Laps........	54.02	97.06	109.84	167.44	290.54	395.20	553.56

Cost of Reg. Alloy Steel Studs and Nuts for Companion Flanges	10.90	19.40	24.70	45.80	76.80	134.50	184.00
Cost of New Alloy Steel Studs and Nuts for Companion Flanges	14.17	25.22	32.11	58.54	99.84	174.85	239.20
Cost Savings in Steel by Elimination of Integral Flanges	15.68	27.84	35.04	54.88	89.92	127.20	180.80
Cost of Regular Alloy Steel Bonnet Studs and Nuts	7.80	9.94	13.36	26.90	45.75	61.40	82.00
Cost of New Alloy Steel Bonnet Studs and Nuts	10.14	12.92	17.36	34.97	59.47	79.82	106.60
Total Savings with Regular Alloy Bolting	88.40	154.24	182.94	295.02	503.01	718.30	1000.36
Total Savings with New Alloy Bolting	94.01	163.04	194.35	315.83	539.77	777.07	1080.16
Cost of Flgd. Valves Including Comp. Flgs. and Bolting	410.80	718.90	845.30	1390.40	1959.20	2686.00	3752.50
Cost of Welded Valves	315.79	554.86	650.95	1074.57	1419.43	1908.93	2671.34
Percentage Saving	**22**	**23**	**23**	**22**	**27**	**29**	**29**

Summary.—The welding of valves into piping, including the welding of the bonnet joints, particularly for higher pressures and temperatures, offers the real solution to the problems encountered with flange joints.

As the stresses in welds are of the same magnitude as those of the pipe walls and relatively low in comparison to the stresses imposed upon flange-joint bolting, creep is not an important factor. Consequently, the maintenance required on welds during the life of the installation is practically nil, whereas flange joints require rather frequent and expensive servicing in order to maintain them absolutely tight.

The pulling up of bolts when assembling the valves and installing them into pipe lines requires a great deal of man power due to the high torques necessary on the wrench levers to properly stress the bolting and assure original tight joints. This operation is both tedious and often hazardous. Although arc welding of heavy valve and pipe sections is also time-consuming, it only requires a welding operator and his helper to complete the assembly after the parts are properly aligned.

The adoption of valves having all joints welded effects an enormous saving in weight amounting to approximately 50 per cent over flanged valves, including their companion flanges and bolting members. This weight reduction also makes it possible to exercise economies in pipe hangers and structural supporting members in a piping installation. Furthermore, heat insulation is easier applied to welded joints in comparison to flanged joints as it is continuous, consequently, additional savings result from this phase.

The cost of welded valves, as installed in a piping system, will eventually amount to 25 per cent less than flanged valves, when the demand is sufficient to build proper equipment for their economical production. This is quite a substantial saving when one considers that the prices of 1500 pound valves including flanges and bolting range from \$410.00 on the 4″ size to \$3752.00 on the 14″ size.

The combined savings, including original cost, supports, insulation, and elimination of practically all maintenance work of costly nature would amount to colossal figures when considering the life period as being approximately twenty years.

Power plants, industries and mankind would benefit in lower costs of power production, processing of numerous products and reliability of equipment to serve the general public.

Chapter XI—Modernizing Michigan's Largest Brewery With Arc Welded Piping

By R. C. Doremus,
Refrigerating engineer, George B. Bright Co., Detroit, Mich.

When the average layman drinks a glass of beer, he has little conception of the plant equipment required and the important part played by refrigeration in producing it.

Refrigeration might be called the "heart of the brewery" on account of the absolute necessity of split-degree temperature control throughout the process. As in other large refrigeration industrial plants, ammonia is the refrigerant used. The liquid and suction vapors are in such tremendous volume that the method of handling and controlling them is very important and deserving of comment. Being a toxic refrigerant, ammonia must be handled with great care to prevent any leakage from the system. Do you like a small ammonia leak? Does anyone like any kind of an ammonia leak, small or large? To the novice or layman, a small leak is distressing and choking, and, still more, spells fright and panic. To the plant owner, it is all this, and more: it is demoralizing to the workers, interrupts the production schedule, causes a tarnishing and corrosion of brass and copper parts, possibly a spoilage of the plant product, a monetary loss represented by the value of the ammonia lost to the atmosphere, and, if severe, may mean the hospitalization of one or more men, and loss of production not usually covered by insurance. In short, an ammonia leak means time and money lost. Such losses are preventable by arc welding and therefore should not be tolerated.

Prior to the development of the art of arc welding, it was customary to make all ammonia piping joints and connections with screwed threads and flanged joints, all of which are potential ammonia leaks in the piping system. It will be the purpose of this article to describe how these have been greatly eliminated in a large brewing plant.

The brewing industry, with all its ramifications from the growing of grains to the brewing of the product and its distribution and consumption, represents the sixth industry in the United States.

The Stroh Brewery Company, in Detroit, is the largest brewery in the State of Michigan and has a capacity of 3000 barrels per day. Its facilities and manufacturing equipment are exemplary in the brewing profession. Yet, prior to 1935, this plant had antiquated ammonia compressors, condensers, etc., and the ammonia piping was put up with flanged joints, the apple of perfection twenty years ago. This comprised 750 tons of refrigeration capacity and over 100 miles of ammonia piping, large and small, in its twenty odd buildings.

The amount of ammonia normally charged in this one refrigerating system was enormous and the annual losses, barring accidents, would pay a very good man's yearly salary. The Stroh Brewery Company, like

many others, has prospered with these refrigeration handicaps—not on account of them, but in spite of them.

In 1935, they decided that it was time to revamp the equipment and piping. This was not an easy task as it might have been in a new construction job, for whatever changes were to be made, had to be accomplished without interruption to the manufacturing schedule.

Decision was made to discard all old refrigeration equipment and replace by new, and, concurrently, to replace all of the ammonia piping lines, which were screwed and flanged, with arc welded piping connections.

This was more of a problem than doing a small bench welding job for it naturally had to be done in place in the field and in a piecemeal manner. Hence, a comprehensive plan was outlined for carrying on the work without diminishing capacity or impeding production, by preparing work as far as possible in the shop, assembling parts and then cutting in the connections in each department.

This schedule was only well started when the owners decided to construct a new $1,500,000 stock house—a cellar house of steel and brick construction 8 floors high with cooperage capacity of well over 100,000 barrels. This was to be equipped with refrigeration piping totaling approximately another 75 miles—no small item—most of which was 2″ continuously welded wall coils.

Accordingly, the schedule was rearranged to include this project, which, incidentally, also brought about still more major changes in equipment. Plans and specifications were prepared to co-ordinate the

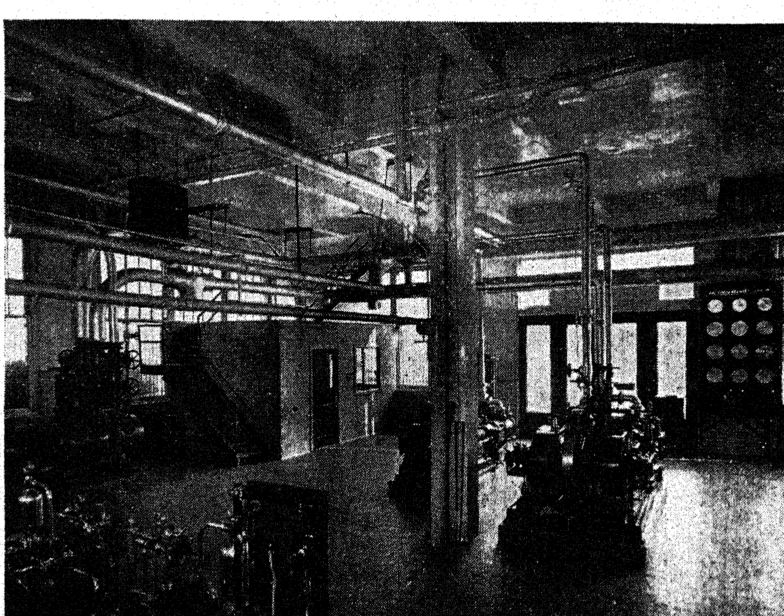


Fig. 1. New direct-connected 4600-volt engine type synchronous motor. Note arc welded piping.

various trades involved and the work started. This was built as planned.

All of the former ammonia compressors, condensers and receivers were removed and sold or junked. These were replaced by seven new horizontal double-acting ammonia compressors, six of which are driven by four-valve steam engines, and the seventh by a direct-connected 4600 volt engine type synchronous motor as shown by photograph, Fig. 1. This photo also shows some of the arc welded piping.

Branch Ammonia Pipe Connections.—All of the former flanged ammonia piping and steam piping mains were removed part by part in a piecemeal manner along with removal of each machine it had served. Caps were arc welded on the ends of the mains and feeder branches while this work was going on, to permit the work to proceed while the remainder of the plant equipment handled the refrigeration load of the brewery. As each new compressor concrete foundation was poured and prepared for a new machine, the suction and discharge manifolds for double suction line connections were arc welded from standard welding fittings, and likewise planned for final assembly to its machine. Then one compressor and its engine were set on the foundation, lined up and bedded in place.

Beside the manifolds for the ammonia compressors, the remainder of the 5″, 6″, 8″ and 10″ discharge and suction piping connections had to be prepared. This ammonia piping was to conduct large volumes of ammonia vapor under various pressures from 10″ vacuum to 200 lbs. per square inch, for there is also an ice cream manufacturing

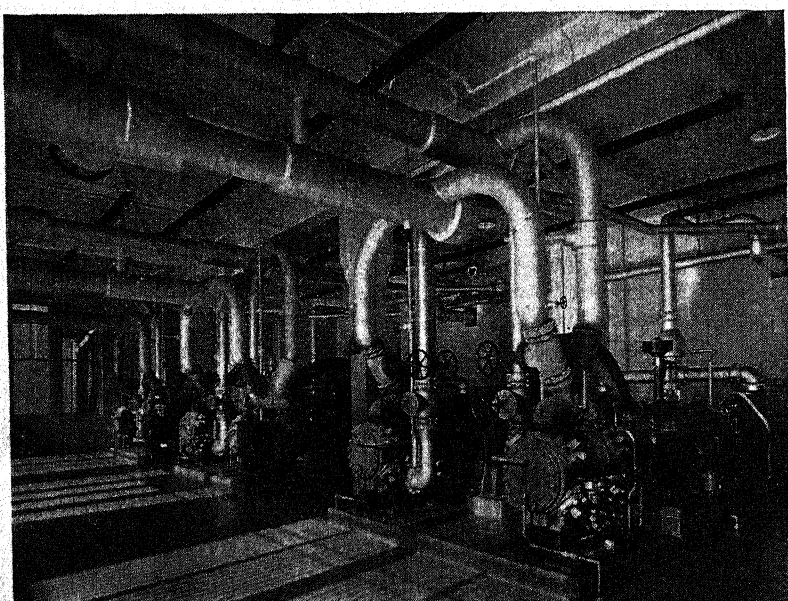


Fig. 2. Arc welded piping connections contribute to the neat appearance of the engine room.

plant operated in connection with this brewery, and it was essential that the piping be designed with broad sweeps and bends to avoid high pressure drops from sharp bends and cast fittings.

Also, the linear expansion and contraction due to line temperature changes had to be taken care of in the design with swing hangers and long-sweep bends to take the resultant movement without excessive stress on cast fittings and parts.

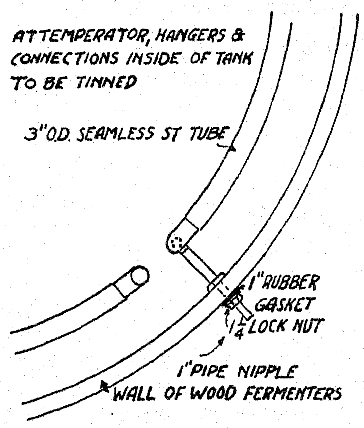
It was decided to use long radius arc welded pipe bends in making these pipe connections, for they not only avoided gas pressure drop and possessed structural strength but also would take movement with resilience and without imperfection, danger of failure, leaks and shutdowns for repairs.

These advantages seemed sufficient, but the arrangement also gave evidence of thoughtful engineering design, pleasing appearance, and, above all, was cheaper in cost to buy, fabricate and install than would have been possible in a stiffer design of pipe and larger size expensive flanged ammonia fittings of sharp turns which would otherwise have been the logical alternate. The accompanying photograph, Fig. 2, shows some of these many piping connections thus made, and the neat appearance of the brewery engine room.

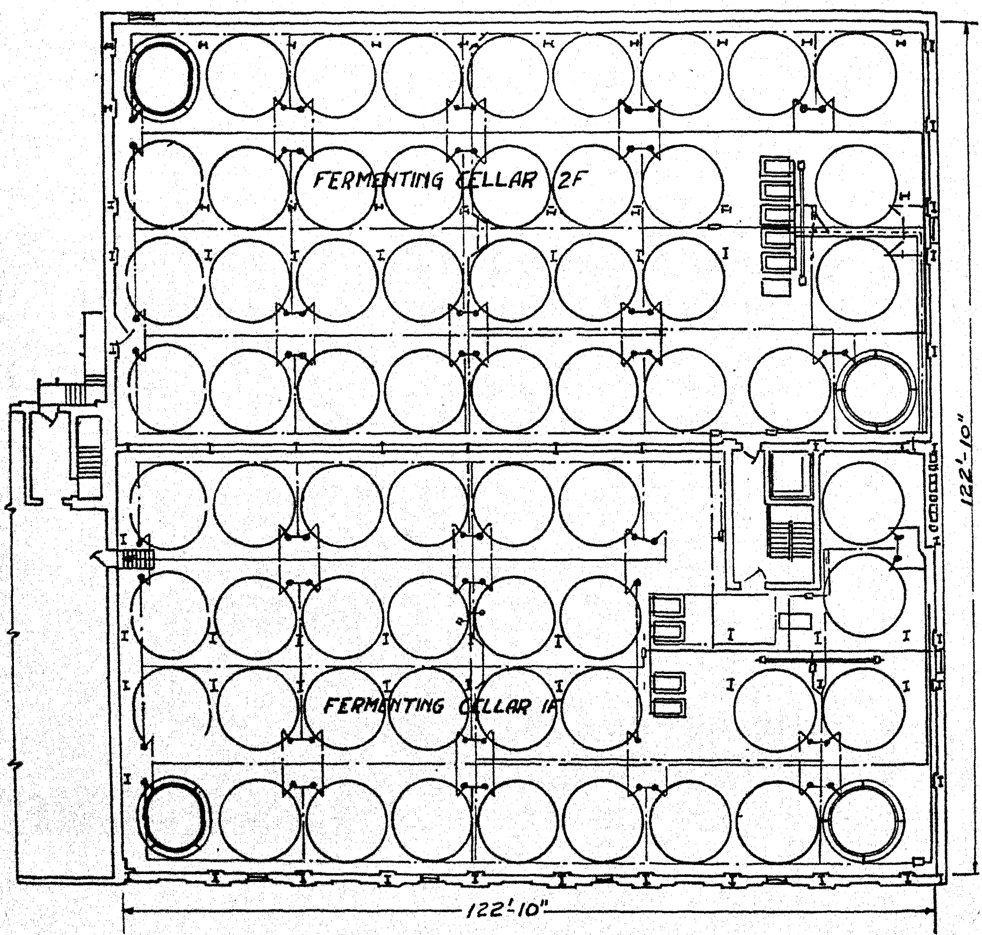
It is customary practice to equip each ammonia suction line with a suitable suction strainer to catch dirt and scale and prevent same from entering the compressor cylinders. This plant comprised three ammonia suction lines of different suction pressures connected with the seven new ammonia compressors, totaling 1000 tons of refrigeration capacity. It was considered best to make these strainers and strainer bodies large enough to accommodate two compressors on account of their twin arrangement. However, there were no such items of this size and capacity procurable as stock equipment from any manufacturer. Therefore, in keeping with our preference for arc welding, it was decided to make them to our own design and dimensions. These were made of 12″ steel pipe 48½″ long. The flange at the end would have been omitted if possible, but this was necessarily included to facilitate removing the strainer for periodic cleaning.

Ammonia Accumulators.—In a brewery of this size, many ammonia accumulators or suction separators are needed to trap out ammonia liquid from the suction vapor to protect the compressors from serious damage. Dozens of ammonia accumulators were built of seamless steel extra heavy pipe with arc welded construction to exact dimensions to suit the conditions.

Ammonia Liquid Precooler.—This refrigerating plant circulates over 400 pounds per minute of liquid ammonia. It was desired to precool this liquid ammonia for increased plant efficiency. This item of equipment was designed and built of arc welded steel construction at an extremely low cost of approximately $80.00, whereas it would have cost about eight times this amount even if procurable from a manufacturer. This illustrates a very good example of welding economy in special equipment.



TYPICAL DETAIL OF
LIQUID INLET
NIPPLE CONNECTIONS



FOURTH FLOOR PLAN

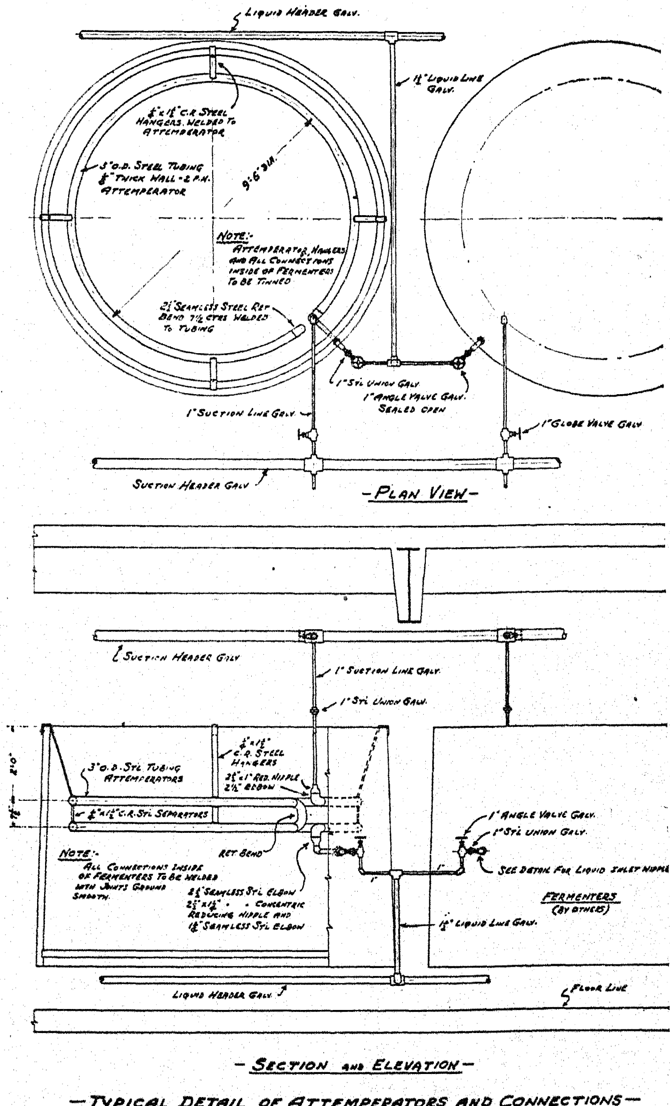


Fig. 3. Piping arrangements of flooded system. See also page 947a.

Ammonia Piping Mains.—The ammonia piping mains, comprising several miles in length were almost wholly installed with arc welded joints and connections. The only places where flanges and welding necks were used were at flanged valves, which necessarily had to be done this way, and at a few other places that were optional for convenience.

Steam Supply and Exhaust Lines.—The steam supply at this plant is 150 lbs. saturated steam, while the exhaust is 26″ vac. These steam and exhaust lines were planned and installed with arc welded joints and a minimum of flanges. These lines varied in size from 5″ to 24″, with standard welding fittings. Unfortunately, no photographs could be made of the exhaust lines which were arc welded for these are buried in trenches and tunnels below the floor. This further simplified and enhanced the appearance of the machine room. This arrangement was also planned to prevent the machine room from becoming excessively heated by their exposure.

Fermenting Tank Attemperators.—Fermenting beer wort generates heat which must be removed during the fermenting process to keep the wort at the desired bath temperature. This was done forty years ago by "swimmers" or blocks of ice floating in copper pans or floats. In most of the present-day breweries, this has been replaced by a copper coil in each fermenting tank, through which cold brine is circulated for refrigeration.

In the Stroh plant, it was decided to change the brine attemperators to flooded ammonia attemperators, thus avoiding the possibility of brine leaks and spoilage and at the same time improve the plant efficiency by eliminating the two temperature differences in transferring the heat directly from the fermenting beer wort to the ammonia refrigerant. This called for steel construction suitable for ammonia use for copper cannot be used with ammonia, and yet it had to be clean and sanitary, also impossible to rust.

The answer to this problem was 2½″, circular and oval, heavy ammonia steel pipe coils bent to shape, arc welded together in each tank and finally tinned on the outside by hand. These were fabricated accordingly in 155 fermenting tanks and connected together with welded ammonia branch and main piping connections in three mammoth flooded ammonia systems, for they are situated in three buildings, with automatic ammonia float control valves and accumulators also of welded construction. This is a revolutionary idea for, prior to the art of arc welding, brewery engineers and architects were loath to use flooded ammonia coils submerged in tanks of fermenting beer wort on account of the danger of ammonia leaks spoiling the beer. However, this arrangement was made possible by arc welding, and, so far as we know, this is the only installation of its kind in the United States, if not the whole world.

The piping arrangements of these flooded systems are shown on Fig. 3.

Later, we decided to equip four closed fermenting tanks with similar welded steel attemperator rings, but in this case we used 3½″ O.D. 18-8 stainless steel tubes with ¼″ thick wall, long radius bends of the same material and arc welded them together inside the closed tanks.

A small portable ventilation system composed of a fan and flexible ducts was necessary to provide fresh air in these closed tanks so that the welding gases would be removed and a livable atmosphere provided in which the welder could work.

All hangers, fittings and stuffing boxes in the tank heads were likewise made of 18-8 stainless steel and all welding was done with 18-8 coated welding rod stock.

Spray System.—The refrigeration capacity of 1000 tons required a large amount of cooling water. The roof of the new stock house was chosen as an ideal location for a spray deck.

In keeping with our preference for arc welding, all main and branch piping connections, varying from 4″ to 16″, were arc welded. This system handles 4800 G.P.M. of water and represents the largest spray cooling water system in the State of Michigan. Low cost, resilience and corrosion were the principal benefits in this installation.

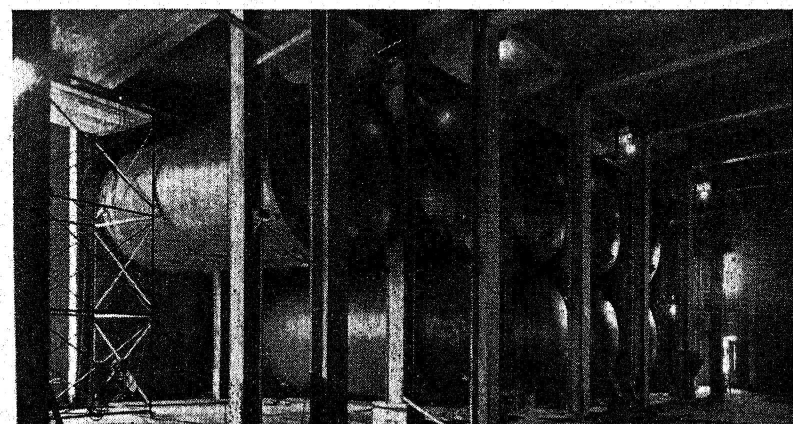


Fig. 4. Arc welded glass-lined stock tanks.

Stock Tanks.—Over 100,000 barrels capacity of stock is held in one-piece arc welded glass lined steel tanks which were installed in double deck arrangement. These were made, and installed as shown by the photographs, Figs. 4 and 5. No attempt is being made in this article to describe them, their handling, methods of support, etc., for that would make a lengthy article of itself. However, mention is here made of them to indicate how much this large brewery depends on arc welding methods in its piping and equipment.

Cost of Making Screwed Joints.—The cost of making screwed and flanged ammonia piping joints has long been realized and is shown by a summary Table I.

TABLE I—COST OF MAKING SCREWED PIPE JOINTS

Pipe Size	3″	4″	5″	6″	8″	10″	12″
Cut to length	.20	.30	.55	.70	1.00	1.50	2.50
Cut 2 threads	.40	.60	1.10	1.40	2.00	3.00	5.00
Clean threads	.10	.10	.10	.10	.11	.12	.15
Cost of 2 flanges	3.12	3.90	5.04	9.60	18.00	19.80	26.40
Cost of 1 gasket	.07	.09	.10	.16	.22	.32	.39
Cost of 4 or 8 bolts	.34	.54	.75	.75	1.10	1.65	1.89
Cost of making up	.38	.38	.45	.53	.60	.68	.75
Cost of assembling	1.12	1.20	1.69	2.25	2.80	3.85	4.50
Total	5.73	7.11	9.78	15.49	25.83	30.92	41.58

Cost of Making Arc Welded Pipe Joints.—The cost of arc welding piping joints was not so well established, at least by ourselves, although we know it would compare favorably with the cost of screwed joints. Accordingly, a study was made on several joints of each size during the progress of the installation and the resulting cost is given in Table II.

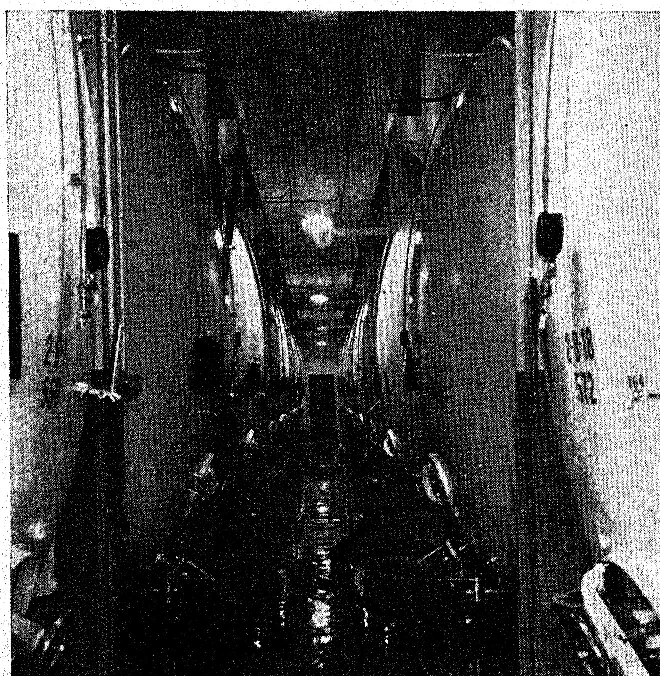


Fig. 5. Arc welded glass-lined stock tanks installed.

TABLE II—COST OF MAKING ARC WELDED PIPE JOINTS

Pipe Size	3"	4"	5"	6"	8"	10"	12"
Cut to length and scarfing	.20	.30	.55	.70	1.00	1.50	2.50
Assembly cost	.57	.57	.82	1.12	1.42	1.88	2.25
Cost to weld	.96	1.28	1.60	1.92	2.56	3.20	4.80
Aligning	.32	.43	.53	.64	.85	1.07	1.60
Total	2.05	2.58	3.50	4.38	5.83	7.65	11.15

The above tables do not include cost of trucking, bills of material, checking tally sheets, shortages, invoicing, checking invoices, etc., which are more for screwed fittings than welded joints but cannot be very well reckoned in dollars and cents.

The power cost involved in welding is not shown in this tabulation nor is any power for cutting threads. These items are quite inconsequential in consideration of the larger items involved, especially inasmuch as most plant owners buy primary power at a very low rate.

A frank comparison of the total costs involved in making ammonia screwed and flange joints as compared with making the same joints by the arc welding method indicates the large saving in cost alone in favor of arc welding, even if we disregarded the many other advantages in this method of fabrication.

Pipe Coils.—The cellars of the Stroh stock houses are cooled by galvanized steel pipe wall coils and the total involved represents over 100 miles in length. These coils are electrically butt welded endless coils, galvanized after fabrication, with a minimum of screwed joints in making the connections.

Tightness.—In all the welds made in piping in this plant, the pressure tests for tightness showed only three leaks, and these were very easily made tight. No leaks have developed during the past year nor are any contemplated. The owners and ourselves are well pleased with the results obtained and naturally we are strong proponents for arc welding.

Emergency Use of Arc Welding.—One interesting event occurred at a very crucial point in the erection program which it might be well to relate to illustrate the real value of arc welding in emergency.

We had taken out one of the old compressors entirely and moved a new one onto the new concrete foundation in its place. We had shut down the second machine and disconnected it from the exhaust line. This meant that their third compressor, a 250-ton cross compound steam corliss driven compressor, would be depended on to handle the refrigeration load until the new compressor was connected in on the line. On a Saturday afternoon, this machine balked and stopped, leaving the brewery with no refrigeration and imperiling many thousands of barrels of stock in process. The owners were frantic at this turn of events and feared a large loss was imminent. We hastily lined up the compressor and synchronous motor drive with electricians, pipe fitters, machinists and welders working on top of one another and often in each other's way. It would have been impossible to connect the compressor to the ammonia lines hurriedly with screwed pipe joints and flanged

fittings. However, we realized the connections could be arc welded hurriedly and so proceeded on this basis. We finished the job and had the compressor running on wedges before the light of a new day and this saved any loss of the stored product. Is it any wonder the owners strongly praise arc welding?

Conclusion.—We have been complimented a number of times on the neat appearance of the machine room, which is the obvious impression on a casual visitor, but the big advantages which count for so much in a large manufacturing plant such as this are as follows:

1. Low cost of making joint.
2. Avoiding high cost of large-size cast ammonia fittings.
3. Avoiding delays in schedule due to orders, fabricating, shipment and receipt of such fittings, many of which are special due to large size.
4. Affording independence from outside sources of material.
5. Permitting sweeps and bends to avoid friction pressure drop.
6. Affording resilience for stresses and movement due to expansion and contraction from temperature changes.
7. Absence of ammonia leaks.
8. Permitting exact dimensions as desired instead of dependence on manufacturers' standards.
9. Permitting piecemeal changes and blanking ends for progress.
10. Affording a better appearance of machine room.
11. Affording cheaper and more efficient pipe covering, with better appearance, by eliminating flanges and flange covers.
12. Permitting any later additions by welding instead of requiring advance planning and foresight and the addition of blind tee fittings.
13. Eliminating ammonia leaks through arc welding, by which we save the cost of ammonia to recharge the system to replenish the leakage.
14. Saving the shutdown time required to repair leaks.
15. And, a point that is very essential and yet so often overlooked, saving the loss in production caused by maintenance shutdowns to repair leaks.

We are still making additions and changes in this plant, which schedule has been spread out over a three-year program. Accordingly, we have had no good opportunity to determine how much we have saved in ammonia leaks. The plant formerly required a recharge of 2,000 pounds of ammonia per month, but we have every reason to believe this will be only 25% of this amount, or possibly less, from now on, which saving will be due principally to arc welded connections and will represent about $300.00 per month.

The average size of arc welded pipe connection in the Stroh brewery is 8″. The cost of an 8″ screwed and flanged joint is $25.83 whereas

the cost of an arc welded joint of this size is only $5.83, which affords an average saving of 77.8% by arc welding over the former method.

If this were adopted by the industry generally, the gross saving of making piping joints would be almost incalculable on account of the tremendous scope of refrigeration in industry. It could very well average $5,000.00 per plant for 3000 plants, on a total initial investment saving of $15,000,000, and an annual saving of $1,000,000 in ammonia saved.

Large industrial refrigeration plants such as breweries, ice manufacturing plants, cold storage and ice cream plants use considerable tonnage capacities of ammonia refrigeration and form an excellent untouched field for arc welding. Their piping systems are so ramified that they contain many hundreds of screwed and flanged joints that are potential ammonia leaks, and this condition exists although welding rod is cheaper in cost than ammonia at eighteen cents per pound. New plants will certainly use arc welding methods wherever possible and old ones must modernize if they hope to match the livelier competition.

SECTION IX

MACHINERY

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SECTION IX
MACHINERY

Chapter I—An Arc Welded Rotary Planing Machine

By John Thomson,
Works director, Sir William Arrol & Co., Ltd., Dalmarnock Iron Works, Glasgow, Scotland.

There are many parts of standard machines, where large numbers of similar parts are required, which may with advantage, as regards both economy and utility, be made of weldings instead of castings. The advantages are much greater, however, where a machine has to be made on short notice for a special job, and where only one of each part may be required.

In such cases, stock material may often be utilized for the weldings, resulting—especially in the present congested state of the foundry trade—in the machine being completed in a small fraction of the time required to make the machine with castings.

This reduction in the time required to obtain the raw material, together with the important saving in time and cost due to the elimination of pattern-making and also the scope provided by weldings for the

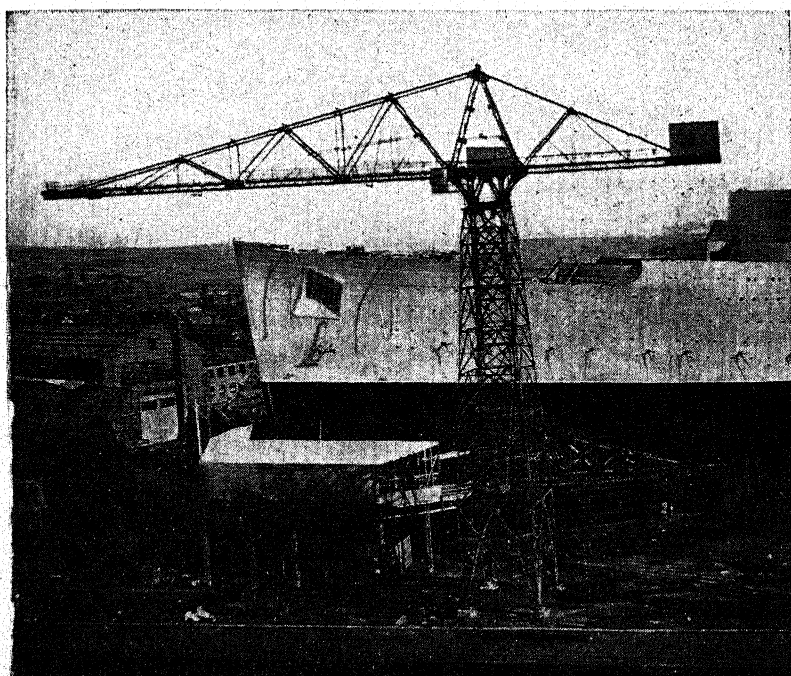


Fig. 1. Type of tower crane, production of which led to fabrication of the arc welded rotary planing machine.

simplification of the machining of parts, have enabled us to make several machines for special work which would otherwise have been impossible.

I purpose describing the design and manufacture of one such machine which was successfully put into operation at the end of last year.

One of our standard products is a tower crane used in shipyards. Fig. 1 shows one of these cranes with an Atlantic liner in the background. These cranes consist essentially of a fixed-tower structure with a rotating mast and jib. The rotating portion is supported on a footstep bearing at the bottom of the mast and it is guided at the top with rollers which contact with a vertical path about 14 feet diameter. This path is incorporated in the platform structure at the top of the tower. The platform has an external diameter of nearly 20 feet and as it is necessary to machine the path after it has been riveted to the completed platform structure, a lathe or boring mill was required which would accommodate work up to 20 feet diameter.

In May of 1937 we had on hand orders for eight of these cranes for a naval dockyard and as the boring mill which had previously machined the paths was fully occupied with work of national importance for two years ahead, we had to consider some alternative method of carrying out this work.

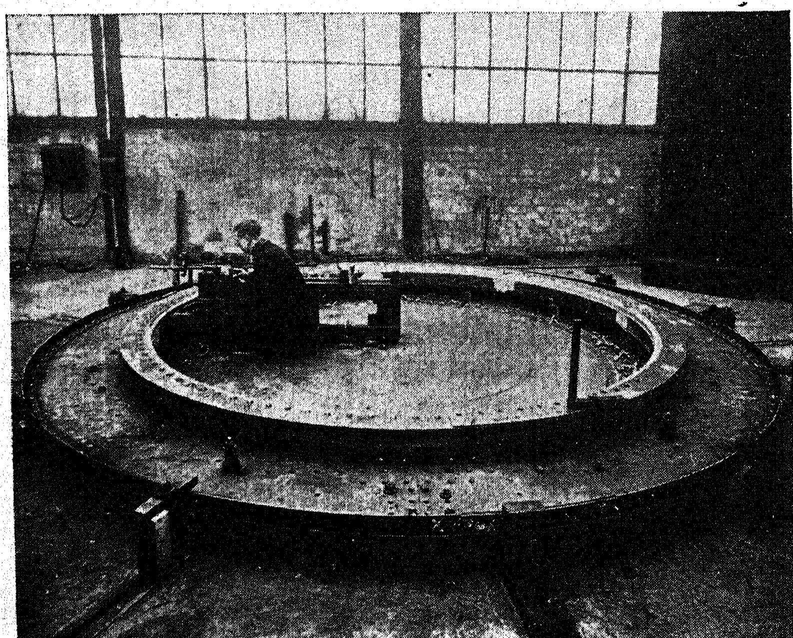


Fig. 2. Rotating table with tool holder bolted to it.

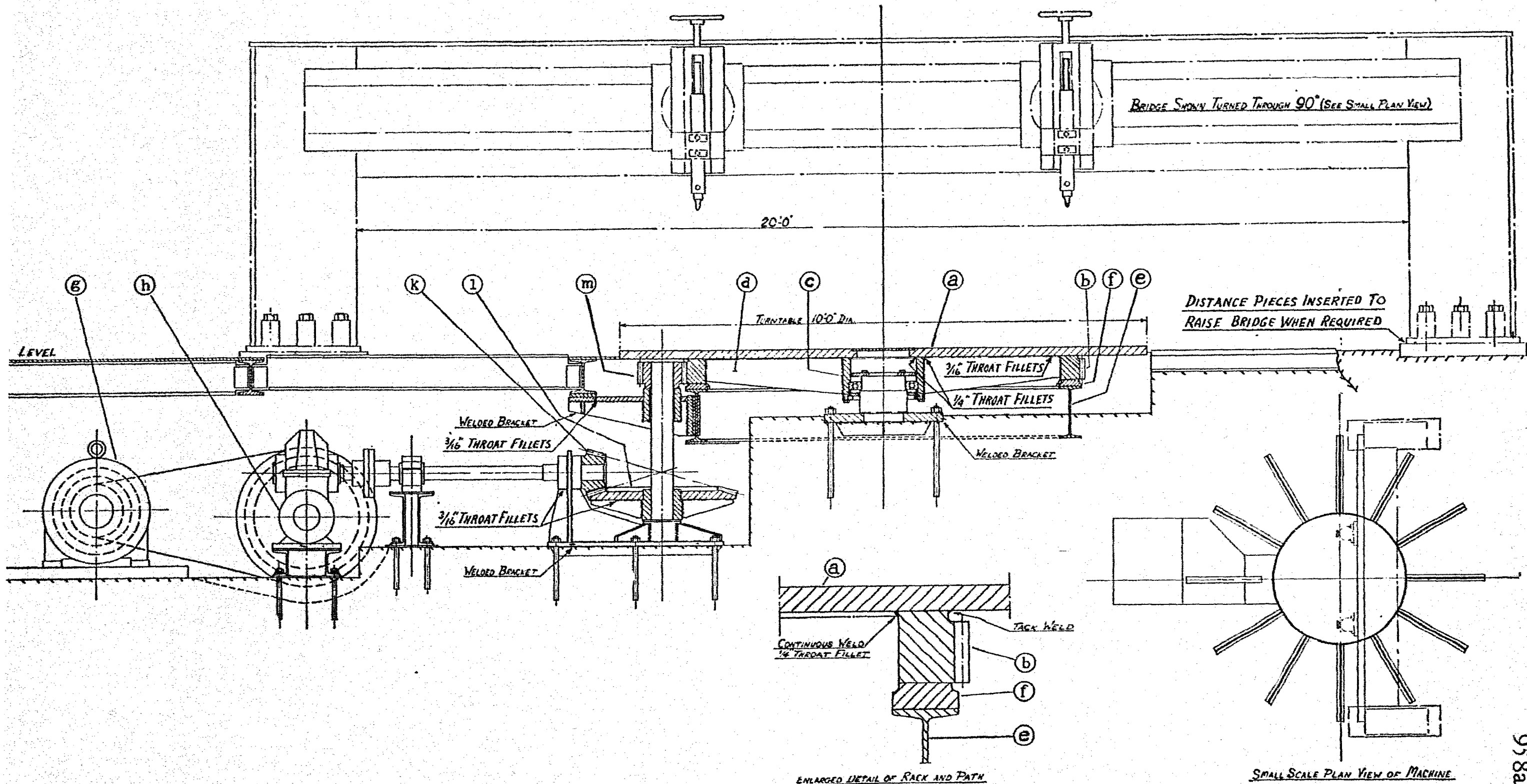


Fig. 3. General view of machine.

We got in touch with the Machine Tool Makers association and all they could offer us was their standard vertical boring mill of 20 feet capacity. Their price for such a machine was £12,000, ($58,320), and the time for delivery was 2½ years.

The work in prospect did not warrant this expenditure and the delivery made the proposition useless for our purpose. We pressed them to consider a simpler machine which would machine the paths without being capable of doing the general work expected of a vertical boring mill, but they informed us that they had not the staff available to design such a machine and that the delivery could not, even with such a machine, be less than two years. They gave a rough indication of the price as £3,000, ($14,580).

These were the circumstances which led us at the end of July 1937 to the decision to design and make in our own works an all-welded machine. The results very much exceeded our expectations as regards costs, date of completion and the efficiency of the machine. We were actually machining a path in nine weeks after the design of the welded machine was started in the drawing office, and the number of hours taken to machine a path compared favourably with that taken previously by the standard boring mill. The finish of the machined surface was also equally good.

The ascertained cost of this machine was £770, ($3742.20), and details are given in the following table.

TABLE I—ASCERTAINED COSTS OF ARC WELDED ROTARY PLANING MACHINE

Steel plates, sections, billets, etc., as purchased	£141. 12. 0d.=	$688.17
Forgings as purchased	7. 18. 5d.=	38.49
Cast iron slipper pads as purchased	3. 5. 2d.=	15.83
10″ worm reduction gear as purchased	34. 2. 6d.=	165.85
Ball bearing as purchased	12. 14. 6d.=	61.84
Cast iron stepped cone pulley as purchased	14. 12. 4d.=	71.04
Gear cutting of rack pinions etc., as purchased	27. 7. 2d.=	132.95
Electric motor starters etc., as purchased	61. 5. 7d.=	297.81
Miscellaneous material as purchased	26. 3. 3d.=	127.15
Foundation work including wages, material, cartage etc.	114. 10. 6d.=	556.59
Drawing office wages	32. 12. 9d.=	158.42
Shop wages in fabrication, machining and erection	130. 15. 9d.=	635.62
Establishment Charges	163. 9. 8d.=	794.53
Total	**£770. 9. 7d.=**	**$3744.53**

In view of the low cost of the welded machine as compared with the indication of costs which we had received from the Machine Tool Association we decided to send an enquiry for a machine to one of the largest non-associated firms. The reply quoted a price of £2,500, ($12,140), and as this did not include electrics and foundations we should add say £150, ($729), making the total cost £2,650, ($12,879). This price included an overhead bridge which was essential for the machine they had in mind, but was not essential for the welded design. The bridge does, however, make the machine of more general utility and we have a welded bridge at present in hand. The estimated cost

of this bridge is £300, ($1458.00), and when this is added we will have at a total cost of £1,070, ($5200.20), a machine more convenient for our purpose and capable of doing any work at least equally well as the machine submitted to us at a cost of £2,650, ($12,879), and it was finished—so far at least as was necessary to machine the paths—in nine weeks compared with the eighteen months required by the tool makers. Excerpts from the shop progress report relating to this machine are given in Table II.

TABLE II—EXCERPTS FROM SHOP PROGRESS REPORT RELATING TO ARC WELDED ROTARY PLANING MACHINE

30th July, 1937.	Drawings started.
6th Augt., 1937.	First drawing issued and table plate ordered from rolling mills.
13th Augt., 1937.	All drawings issued except foundation plan. Table plate delivered and electrical gear ordered.
20th Augt., 1937.	Foundation drawings issued and foundations started. Table plate cut to shape and flattened. Small material being cut to shape.
27th Augt., 1937.	Upper slipper path welded and being machined. To be sent for gear cutting on 30th instant.
3rd Septr., 1937.	Bevel wheel and pinions machined and sent to gear cutters.
10th Septr., 1937.	All gear cutting completed. Slipper path being fitted to table unit. Brackets being welded.
17th Septr., 1937.	Foundations completed and lower slipper path with radial beams grouted in.
24th Septr., 1937.	Complete table unit welded and upper slipper path fine machined on working face. All electrical gear delivered.
1st Octr., 1937	Machine completed, and first job being machined.

The machine consists essentially of a table rotating in a horizontal plane about one inch above the floor level. The driving power was provided by a 25 H.P. electric motor working through reduction gears to a rack welded to the underside of the table. On the floor surrounding the table, plate radial beams were grouted into the concrete. When machining the paths, the work was bolted to these radial beams and the tool holder was bolted to, and rotated with, the table, as shown on Fig. 2. From this it will be seen that the outside dimensions of the work were limited only by the floor space, while the internal diameter to be machined was limited only by the length which the tool holder can safely overhang the table. For machining the external surfaces of smaller work the job is fixed to and rotates with the table, while the tool box is fixed to the radial arms on the floor.

In the machines submitted to us by the machine tool makers the table was about 3 feet above the floor level, and as the work had always to be fixed to the rotating table and the tools always fixed to the bridge, the outside dimension of the work was limited by the distance between the bridge uprights.

One important feature of the welded design is that the whole machine is at or below floor level and when the machine is not in use the floor is available for assembly work. This was in our case an important consideration. When the overhead bridge is completed it will be made movable as there are many jobs which can be done more efficiently without it and the floor can still be cleared for other work.

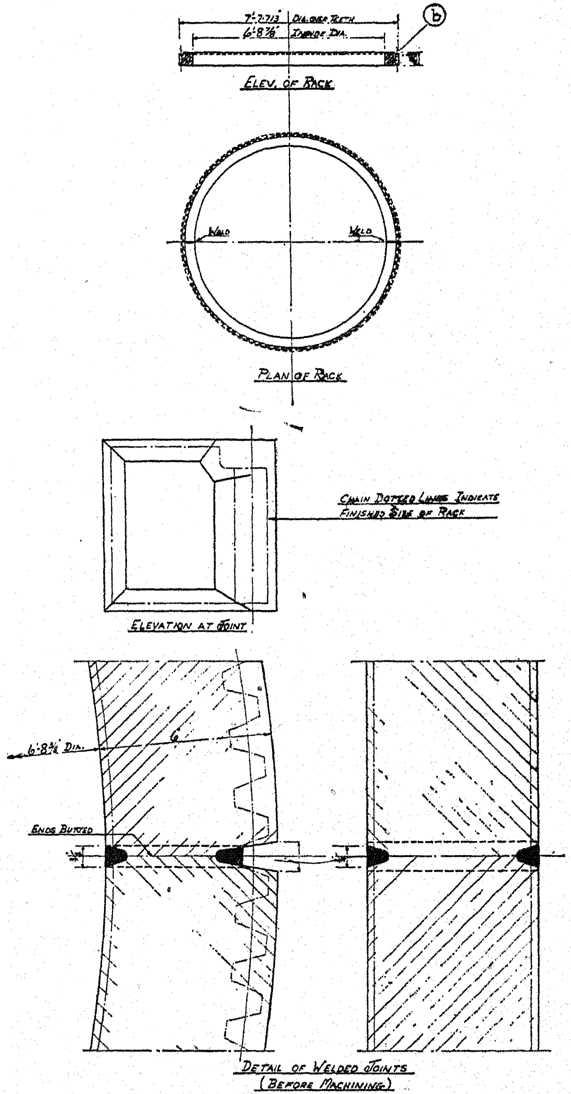
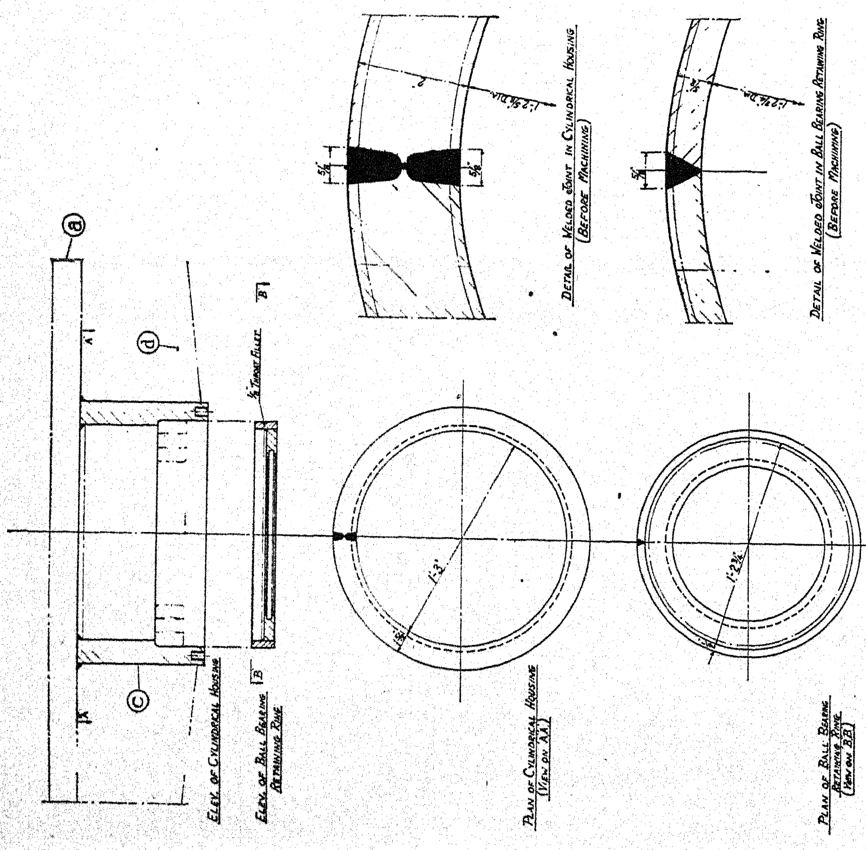


Fig. 4. Detail of upper slipper path.



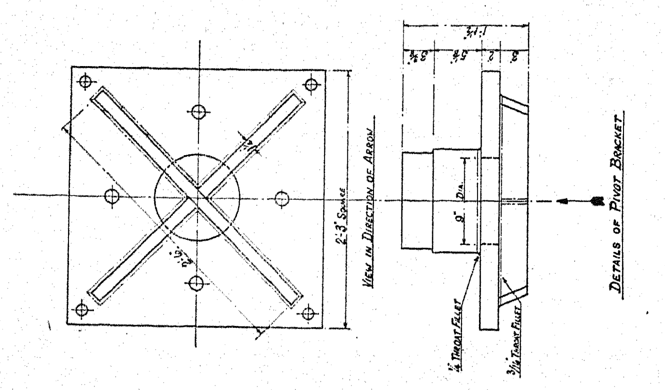


Fig. 5, (left). Cylindrical housing for ball bearing. Fig 6, (right). Details of pivot bracket locating the center ball bearing.

Fig. 3 gives a general view of the machine. The table "a" consists of a rolled plate 10 feet diameter and 2 inches thick, to which is welded the slipper path "b" and also the housing "c" for the center ball bearing. The outside face of the slipper path is gear-cut to form the rack for rotating the table. The slipper path and center housing are connected with radial arms "d" which also serve to stiffen the table plate. The lower slipper path "e" is grouted in concrete after being machined on the top surface, and cast iron packings "f" are bolted to this path and carefully trued up by hand scraping. The lubrication of the sliding face is provided by rollers running in oil recesses in these cast iron packings. The electric motor "g" was fitted with cone pulleys to allow the speed of the table to be varied to suit the diameter of the work being machined. The first reduction "h" consists of a standard enclosed worm gear reducer which was purchased. The second reduction, which also changes the direction of the drive, consists of a bevel pinion "k" gearing into a bevel wheel "l". The third reduction is formed of the steel pinion "m" gearing into the rack billet "b". The two pinions "k" and "m" are cut from solid forged bars, but the bevel wheel "l" and all the brackets supporting the gearing were of welded design.

Fabrication.—A detailed description will now be given of the methods of fabrication adopted for the various parts of the machine.

The rotating table was cut to its circular shape by torch burning after which it was carefully flattened in a hydraulic press. The upper

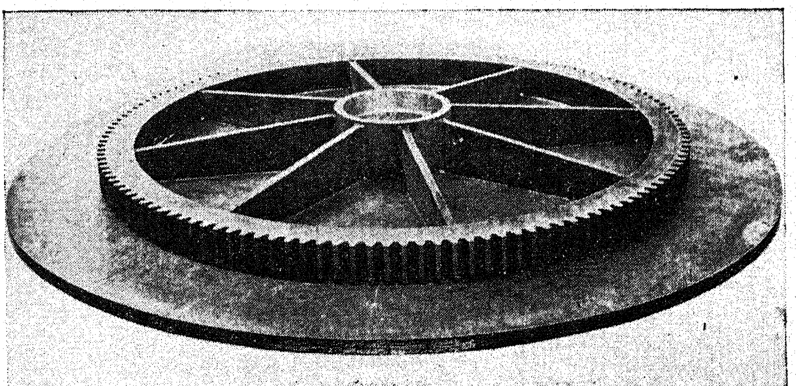


Fig. 7. Complete table unit.

slipper path is detailed in Fig. 4. It was formed of rolled square billets bent into two semi-circles and the end welded together as shown to form a circle. Full strength welds to connect the two halves together were not necessary as the subsequent welding of the path to the table plate was adequate to transmit the driving load on the teeth. The welds were consequently small as shown on the drawing, the purpose of the weld being to hold the parts rigidly together during subsequent machining and gear-cutting. After welding, the ring was machined on all faces and the teeth forming the rack were cut on the outside face.

The cylindrical housing for the ball bearing is shown on Fig. 5.

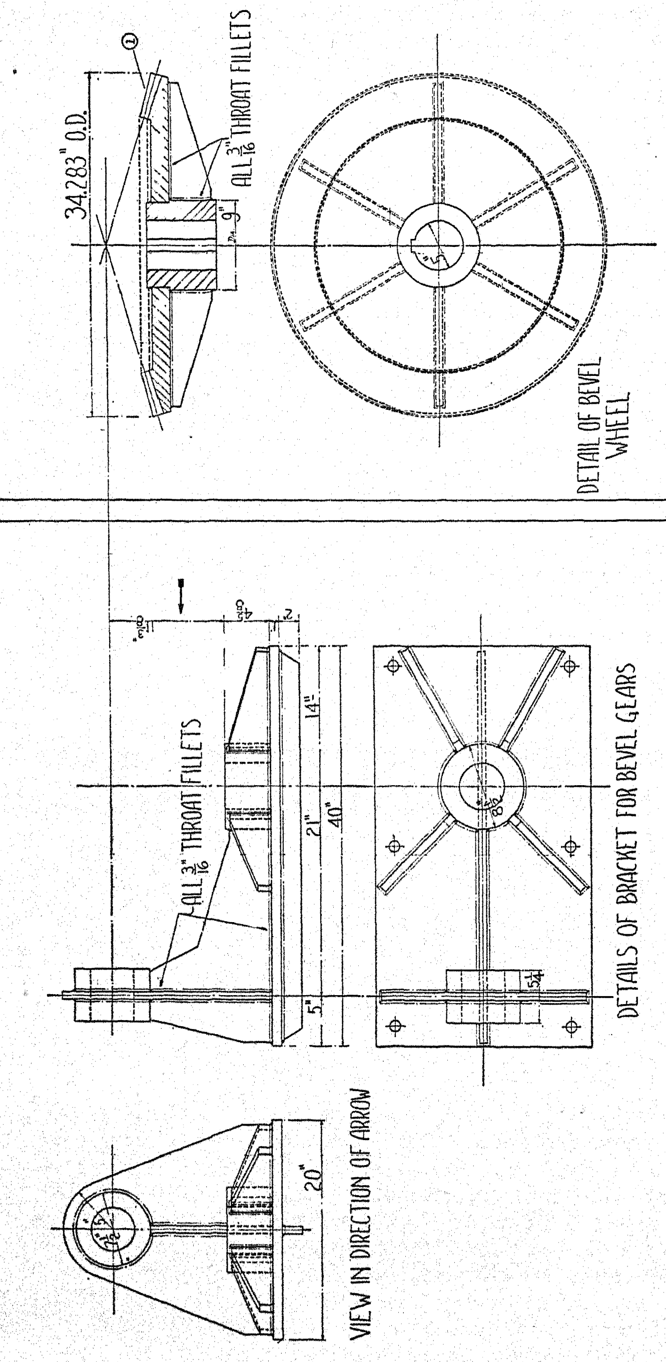


Fig. 8. (left) details of bracket carrying bevels. Fig. 9. (right) bevel wheel.

It was formed of a rolled steel plate 2 inches thick, bent in a hydraulic press to cylindrical form and the longitudinal joint welded as shown. All faces of the cylinder were then rough-machined. The radial stiffening plates were cut to shape by torch. In assembling the table unit, the ball bearing housing was first welded central on the table plate, after which the radial stiffening plates were welded in position. This assembly was then put in a lathe and the outer ends of the radial plates were machined to the exact diameter of the inside of the slipper track ring. At the same setting, the table plate was machined in way of the slipper path so as to give it a true seating. This machining was considered advisable as it was essential that there should be no distortion in the rack teeth when the slipper path was welded in position. For the same reason the final welding of the slipper path to the table—after the former had been fitted tightly over the ends of the radial plate—was made small, being only 1/8" throat thickness. These precautions proved effective as the total distortion when the completed unit was put in the lathe for final machining was under 0.01". This final machining consisted in fine machining the working face of the slipper path and also of the ball bearing housing. The complete table unit is shown in Fig. 7.

The pivot bracket locating the center ball bearing is shown on Fig. 6. It consists of a square slab 2 inches thick with anchoring plates welded on the underside for grouting into the concrete, and a solid forged pivot recessed into the slab. After the unit was welded, the pivot was carefully machined to fit the internal diameter of the ball bearing.

The bevel wheel is detailed on Fig. 9. It was made from a rolled slab 3½ inches thick. This slab was first rough-machined to shape with a central hole 8½ inches diameter. A boss made of rolled bar was machined and fitted as shown. After welding the wheel was finished

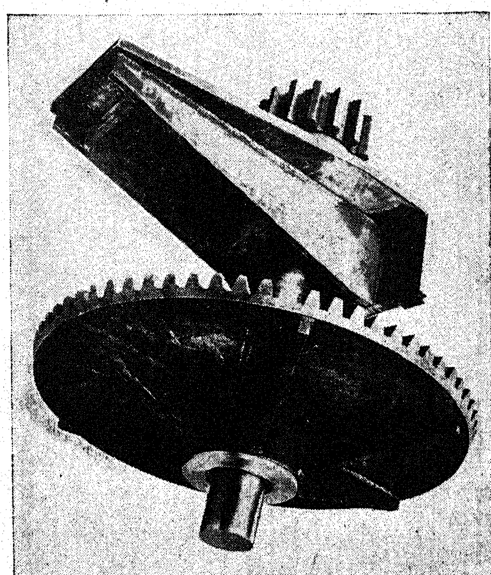


Fig. 10. Wheel with bracket and rack pinion.

to sizes and the teeth cut. This wheel with bracket and rack pinion is shown in Fig. 10.

The bracket carrying the bevels is shown on Fig. 8. It is composed of plates one inch thick with rolled bars forming the bosses, and a stiffening rib along the bottom to form a key in the concrete. This bracket is also shown in Fig. 11.

The saving in cost to our firm by adopting the welded design was, as already shown, £1,880, ($9136.80), if considered simply as a machine to deal with the roller paths, or a saving of £1,580, ($7678.80), if the welded machine was made equally suitable to the cast iron design for general work. By far the greater part of this saving was due, not simply by substituting weldings for castings, but by adopting an entirely new design which allowed methods of fabrication and machining to be adopted which were not applicable to a cast iron design.

To assess the benefits accruing to industry and to the social life of the community generally, we have to consider the peculiar circumstances existing in the first half of 1937. During this period, which followed several years of very severe depression, the engineering industry was asked to largely augment its production in order to deal with a general increase in industrial activity and to accelerate the armament programme. It was also hoped that it would quickly absorb very large numbers of unemployed men. The response was disappointing and the

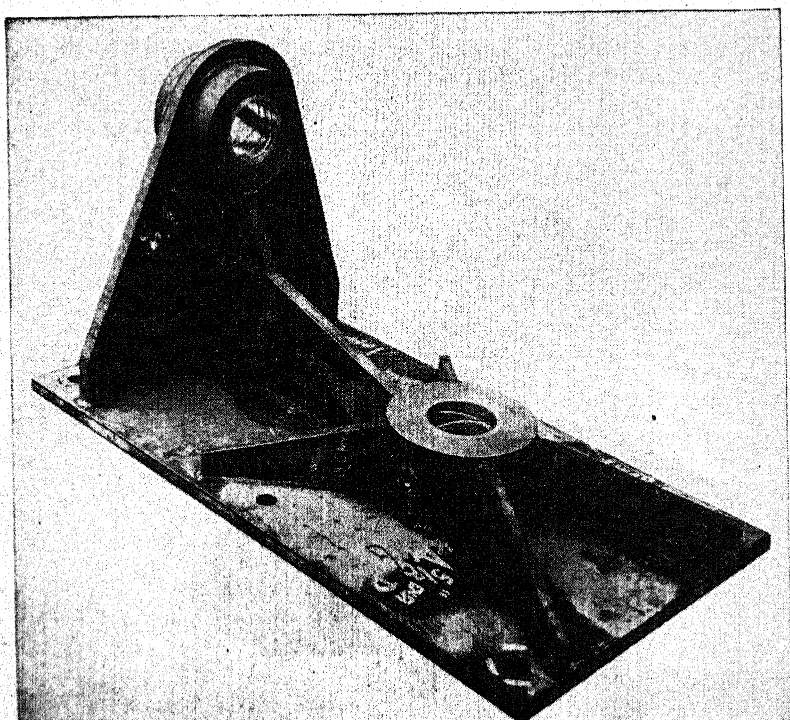


Fig. 11. Bracket carrying bevels.

revival of the whole engineering industry was delayed by the lack of essential materials and machines as well as the scarcity of skilled men in essential branches of the industry. Iron and steel foundries, particularly, were unable to meet the demands made on them and the machine tool makers could not procure the necessary designers and draughtsmen to deal with machinery problems. This difficulty was alleviated, if not solved, by the substitution of weldings made by men with a few months training in place of founders for which a five years' apprenticeship is required, and by general engineering designers doing the work of those who specialized in the machine tool branch of the industry.

By producing the machine I have described in nine weeks instead of eighteen months as required by the machine tool makers, the cranes were delivered to the time schedule, the shipyard allowed to function according to programme and many men were employed in the shipyard who would otherwise have been unemployed.

Many as are the benefits which industry and the community have derived from the use of weldings, one of the most important is the opportunity it has afforded of rapidly supplementing production of the whole or part of essential machines when the branches of the industry, which had specialized in these, were found incapable of meeting the demand for their products.

The machine described is typical of many which have been built in various parts of the country and they have played an essential part in the expansion of the industry as a whole in accelerating the armament programme and in the absorption of a large number of unemployed men.

Chapter II—Redesign of a Cast Iron Planer for Arc Welded Steel Construction

By HAROLD VERSON,
Chief engineer, Verson Allsteel Press Co., Chicago, Ill.

The design and fabrication of all-steel welded machinery has, heretofore, been confined to members which have had to carry unusually heavy loads or to machines whose members were so large that casting would have been impractical. It has been generally taken for granted that machines classfied as machine tools such as lathes, shapers, milling machines and planers are better adapted to cast construction then welded design. The only apparent reasons for this assumption are that the machine tool industry has not been forced to change from cast construction, and it has been axiomatically supposed that cast members are more rigid and will, therefore, be more accurate over a greater period of time.

It is the purpose of this paper to consider a planer which has already been built, and redesign it for welded construction, not only to demonstrate a reduced cost, but almost more essentially to emphasize the following features:

1. Greater rigidity.
2. Less deflection.
3. Less power consumption in operation.
4. Greater possible operating speeds.

No attempt has been made to change the basic design, as the entire point of the demonstration would then be lost. The shapes of the different members have been strictly adhered to, especially with regard to overall dimensions. Any minor changes have been all noted and reasons for doing so have been given. Since the minor parts of the machine such as the shafts, bearings, pulleys, etc. would be the same whether the machine was cast or fabricated, only the largest members will be treated. These are the bed, table, housings, arch and cross rail.

The planer in question is one operating in our plant and has the following general specifications:

Table	86″ wide x 32′ 0″ long.
Bed	72″ wide x 62′ 0″ long.
Distance between housings	138″
Distance under rail	88″
Cutting Stroke	30′ 0″
Total Weight	175,000 lbs.

This machine is shown in Fig. 1. It is evident that a machine of this capacity would not be carried in stock, and since it would only be built on order, a specific pattern charge would be made against it. In the cast iron figures, all pattern costs have been divided over six planers, so that figures shown are one-sixth that of the actual cost.

Table.—The first member to be considered is the table. As stated before, it is 86″ wide x 32′ 0″ long. The average thickness is about 10″, and the finished weight is approximately 47,000 lbs. After adding one-half inch finish for all surfaces, the casting weight would be 52,000 lbs. This is the figure which will be considered in comparison with welded construction. A closeup photograph of the table is shown in Fig. 2. It has five "T" slots running the full length and numerous stop pin holes

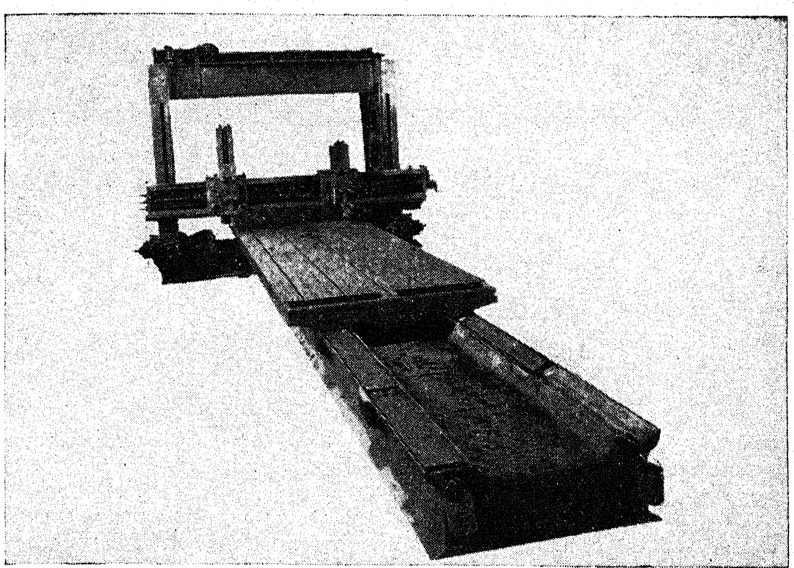


Fig. 1. Cast iron planer which was redesigned for arc welding.

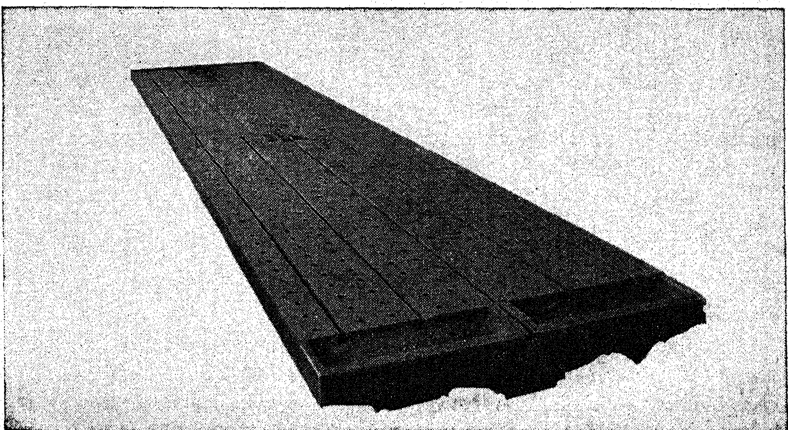


Fig. 2. Table of planer.

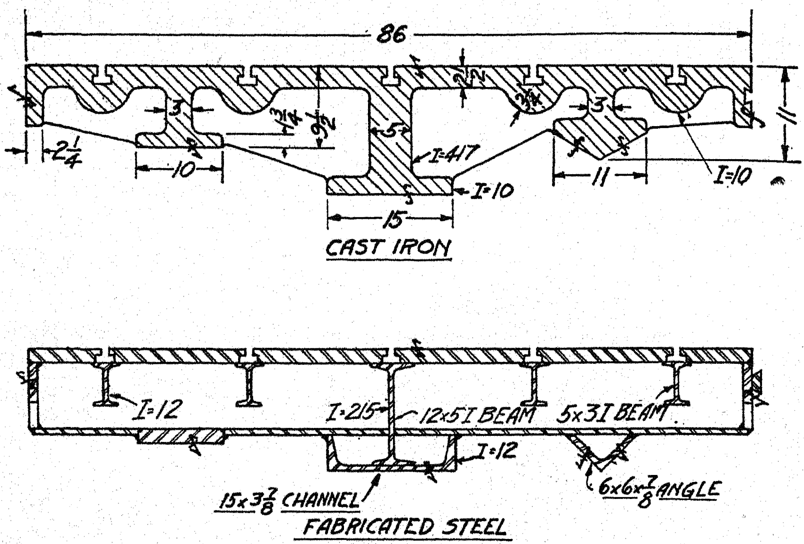


Fig. 3. Cross-sections of table—end view.

for bracing various jobs against the cutting tools. These holes will be disregarded as they are drilled after casting.

To insure smooth, chatter-free and accurate cutting over an indefinite period, a planer table must be unusually well ribbed and reinforced. It must not only withstand heavy shock loads such as careless handling of jobs, but must also hold its shape when undue strain is applied to it by clamp screws. These clamp screws have a tendency to concentrate stresses on very small areas at different points of the table.

The cast table of the planer in question is well ribbed and braced in both directions. An end view in cross-section is shown at top in Fig. 3. Each "T" slot is supported by a 6½" diameter semi-circular section. These sections tend to brace the table at the open "T" slots and also to keep it straight against the strain of the clamping bolts. The center section on which is clamped the rack (not shown), and the two gibways are connected and braced by thirty 1½" thick ribs. These are shown at top in Fig. 4 which is a cross-section of the side of the table. The table is well designed and has withstood the general run of abuse.

In redesigning for arc welded steel construction, it is necessary to construct a member with an equal or better resistance to deflection than that of the cast table. Deflection depends on two factors—the modulus of elasticity of the material and the moment of inertia of the section. In both illustrations, (see top views, Figs. 3 and 4), the moments of

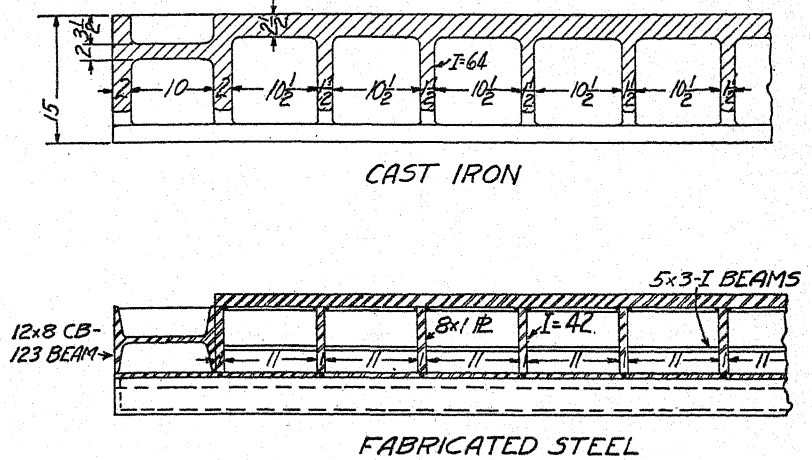


Fig. 4. Cross-sections of table—side view.

inertia of the different sections have been noted. Since the modulus of elasticity of steel is 29,000,000 and that of cast iron is 12,000,000, a steel member to have the same deflection need only have sections with a moment of inertia 40%, or ⅖ that of cast iron sections.

At bottom of Fig. 3 is shown an end view in cross-section of the redesigned steel table. The top of the table is made of five 2″ plates with sides planed to form one-half of the "T" slot. Each open slot is supported by a standard 10 lb. "American I" beam 5″ x 3″ wide running the full length of the table. The moment of inertia of each beam is 12, and that of the semi-circular cast iron section is 10, so that the steel member is approximately three times stiffer and more rigid.

The center member is composed of one 32 lb. "American I" beam 15″ deep x 5″ wide welded to 15″ x 3⅞″ channel, weighing 55 lbs. per foot. The moment of inertia of the beam is 215 and the channel is 12. Compared with this, the center section of the cast table has a moment of inertia of 417 and the lower part 10. This means that the center of the steel welded table is about 25% stiffer and, therefore, will more easily withstand undue strain.

Since the table is unsupported between the two gibways, the actual load of heavy jobs is taken by the cross ribs running the width of the table. These are shown as previously stated in Fig. 4, (top view), for the cast table, and Fig. 4, (bottom view), for the redesigned arc welded member. The cross ribs are made of twenty-nine 1″ x 8″ plates to which are welded the 5″ "I" beams supporting the "T" slots. The moment of inertia of each plate is 42 and the total for the twenty-nine is 1218. Comparing with the cast table, each rib has a moment of inertia of 64 and a total of 1920 for the thirty ribs. These figures

establish the fact that the steel table will have about 40% less deflection under equal loads than the cast table. Each end of the table is made of a 12" x 8" CB beam which form the wells for catching chips. To the bottom of the 1" x 8" plates is welded a 3/8" plate which serves the purpose of keeping the chips from dropping through the drilled holes and falling on the gears or gibways. Incidentally, this was not provided for in the cast iron table. Although this 3/8" plate adds somewhat to the moment of inertia, it has been disregarded.

After having determined a steel design that will be much more rigid than cast construction, it is only necessary to determine the cost of each method. The cast iron table in the rough weighs 52,000 lbs.

52,000 lbs. @ $.045 per pound	$2340.00
Pattern Cost (one-sixth of actual)	$ 72.00
Total Cost	$2412.00

The bill of material showing how the steel table was fabricated is shown in Table I. The total weight is 34,000 lbs. The total welding rod required was determined as follows:

750 feet of 1/4" rod—0.32 lb. per foot	240 lbs.
850 feet of 3/8" rod—0.40 lb. per foot	340 lbs
	580 lbs.
Plus 10 %	58 lbs.
Total	638 lbs.

638 lbs. @ $.095 per pound..........$60.61

The torch cutting cost was determined as follows:

2" plate—180 feet @ $.23 per foot	$41.40
3/8" plate— 96 feet @ $.07 per foot	6.72
1" plate—321 feet @ $.12 per foot	38.52
1 3/4" plate— 33 feet @ $.21 per foot	6.93
Total	$93.57

Before a final cost analysis is made I wish to bring out the fact that it will be necessary to bronze line the gibways because steel will not work with steel without scoring. The cost of the bronze liners is as follows:

2—3/16" x 4" x 32' 0"—182 lbs. @ $.40 per pound	$ 73.60
2—3/16" x 6" x 32' 0"—276 lbs. @ $.40 per pound	100.40
Total	$174.00

The labor cost in fabricating the steel table is as follows:

750 feet of 1/4" rod—1 pass—16 feet per hour	47 hrs.
850 feet of 3/8" rod—1 pass—12 feet per hour	71 hrs.
Saw cutting	6 hrs.

Rough planing (before welding)	60 hrs.
Lineup	24 hrs.
Total	208 hrs.
208 hours @ $.90 per hour	$187.20
200% overhead	374.40
Total	$561.60

We can now determine a complete cost:

Steel—34,000 lbs. @ $2.25 per cwt.	$ 765.00
Welding Rod	60.61
Bronze Liners	174.00
Brass Screws	15.00
Stress Relieving—34,000 lbs. @ $.005 per pound	170.00
Torch Cutting	93.57
Labor	561.00
Total	$1,839.18

TABLE I—BILL OF MATERIAL OF STEEL FOR TABLE

Type of Steel and No. of Pcs.	Designation on Table	Size of Steel	Wt. per Foot	No. of Feet	Total Weight
1 Channel	Top of rack	15 x 3⅜ x ⅞	55	32	1760
1 Angle	R.H. gib	6 x 6 x ⅞	33	32	1056
2 "H" Beams	End wells	12 x 8	40	14	560
4 "I" Beams	Bottom of "T" Slots	5 x 3	10	120	1200
1 "I" Beam	Center rib	12 x 5	31.8	32	1017
1 Bar	Clamping slot	1 x 2	6.72	32	215
1 Plate	L.H. gib	1¾ x 10	59	32	1890
29 Plates	Cross ribs	1 x 8	26.8	193	5172
2 Plates	Side Members	1 x 8	26.8	64	1715
4 Plates	Center top plates	2 x 16	107.5	120	12900
2 Plates	Outside top plates	2 x 8½	57.1	60	3426
1 Plate	Bottom R. H.	⅜ x 42	53	32	1696
1 Plate	Bottom Center	⅜ x 19	24	32	768
1 Plate	Bottom L. H.	⅜ x 14	17.6	32	563

TOTAL WEIGHT..........33,938 lbs.

Compared with the cast iron table we have a saving in weight of 34% or 18,000 lbs., and a saving in cost of 24% or $572.94. The saving in weight would be a great selling factor to the manufacturer. A power test was run on our planer and it was found that 19 H.P. were required to run the table back on the free stroke, whereas only 15 H.P. were required for a full cut on two heads. By using a lighter table, even more rigid than the cast iron table, power consumption could be reduced by 34%, and the table could be returned at a still greater speed.

Furthermore, the pressure per square inch on the gibways has been reduced by 34%, and since the coefficient of friction between steel and bronze is less than that between iron and iron, another power saving is effected. In case of wear, the liners can be easily replaced.

A question may be raised as to whether a lighter table will permit as smooth a cut as a heavier member. This is easily answered by the fact that any planer of much smaller capacity with a table weighing one-fifth as much will make equally as smooth a cut.

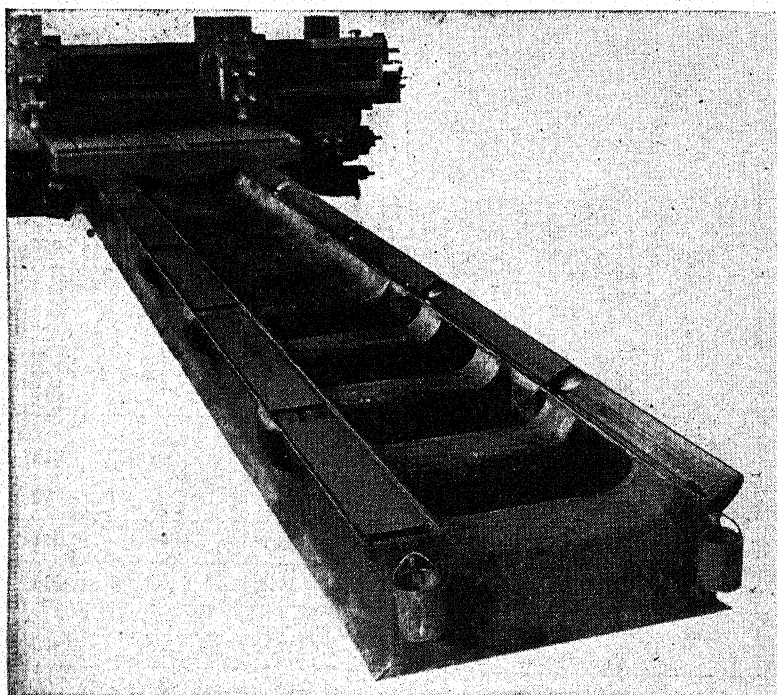


Fig. 5. Front portion of bed.

Bed.—The second member to be considered is the bed. A photograph of the front part of it is shown in Fig. 5. The rest of the bed is the same with the exception of the two large supports at the center to which are bolted the housings.

The construction of the bed need not be quite as heavy as the table, since it remains stationary after installation. However, it must be well

braced and ribbed to insure alignment of the gibways and square cutting over an indefinite period. Since the bed really consists of the two gibways, the ribs need only run between these two. A side view of the bed, partly in cross-section, is shown at top right in Fig. 6. As can be seen, the ribs consist of twenty-eight "U" shaped members 1″ thick. It would have been unwise to cast these any thinner, because of the unusual size of the entire member. The bed is constructed of three separate members—machined, keyseated and bolted together. This was done for three reasons—for easier machining, shipping and handling. The steel bed will be designed in the same way.

A front view of the bed, partly in cross-section, is shown at top left in Fig. 6. A cored slot is provided in the left hand gibway for the return of the oil to the wells of which there are eight on each side. The side supports to which the housings are bolted are extra heavy to eliminate vibration during the cutting stroke. Moreover, they carry the weight of the housings, arch, cross rail and in fact almost every other part of the planer with exception of the table and gears. When redesigning for steel construction, these members can be built much lighter since steel will carry two and one-half times the load with the same deflection. Also, the main members under the gibs can be reduced considerably because the steel table, already designed, will only weigh a little more than half of the cast table. The complete weight of the cast bed in the rough was 54,000 lbs.

In redesigning for welded construction the design has not been altered. The various thicknesses have been merely reduced in proportion to the strength of the two materials and to the best advantage of the flexibility of steel.

A front view as redesigned in steel is shown at bottom left in Fig. 6. The left hand or flat gib has been constructed of two plates. The top one which is made of a plate 2″ x 11″ x 768″ is rough-planed before welding to provide a slot for the oil return to the end wells. In the same operation it is scarfed to provide a bevel for welding to the lower plate. As stated before, the other members have been reduced in proportion to the reduced weight of the table and with the knowledge of the added strength of steel.

The side view of the steel member is shown at bottom right in Fig. 6. In place of the cast "U" members, which were 1″ thick and 12″ wide, has been substituted ½″ plates and 21″ wide. This provides a much stiffer section laterally and does not reduce the carrying capacity vertically. The reason for this is that the combined thickness of all the "U" members in the cast bed is 42″ and in the steel 21″, so that taking advantage of the difference in modulus of elasticity, the steel frame will still have 20% less deflection. The housing supports on each side were reduced materially for the same reason. When bolted in place, the housing together with the weight of the top brace, cross rail and heads, load the vertical members of the support. This is an ideal condition for steel. In the cast iron bed, two 2″ thick ribs were provided, while in the steel construction, these were replaced by three 1¼″ plates of the same height. This assures us that the latter member will have half as much deflection.

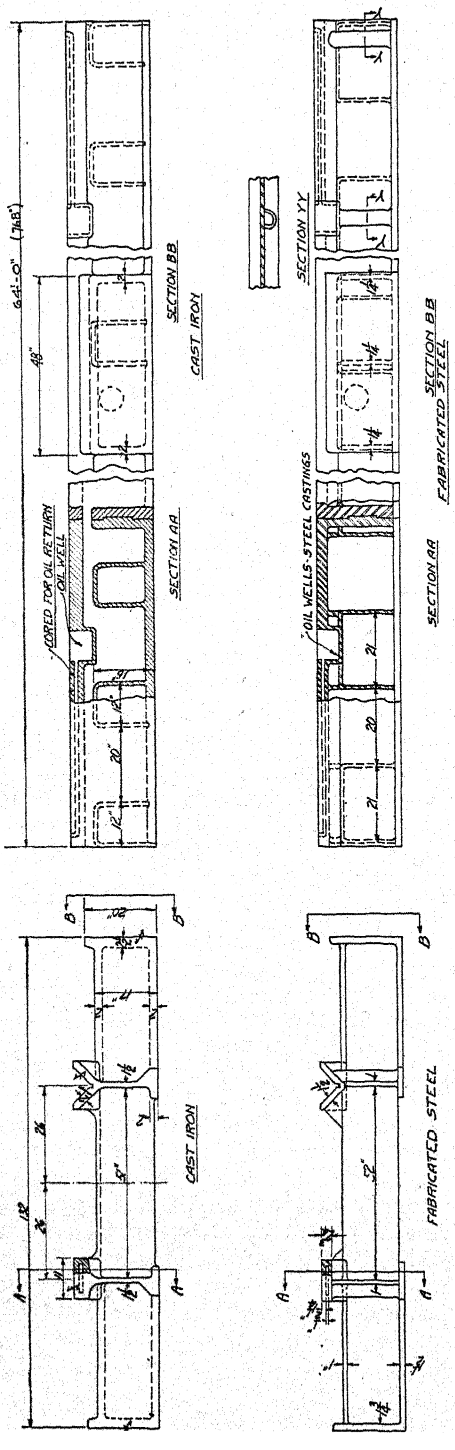


Fig. 6. Cross-sections of bed. Top right—side view; top left—front view, both for cast iron. Bottom, same views for welded steel.

The comparison of the costs of the two is as follows: The actual weight of the cast iron bed is 54,000 lbs. in the rough.

54,000 lbs. @ $.045 per pound	$2430.00
Pattern Cost—(one-sixth actual)	70.00
Total	$2500.00

The bill of material showing the steel used in the steel welded bed is shown in Table II. The total steel used is approximately 42,000 lbs. The total welding rod used was determined as follows:

760 feet of 1/4" rod—@ 0.32 lbs. per foot	243 lbs.
840 feet of 3/8" rod—@ 0.40 lbs. per foot	356 lbs.
	599 lbs.
Plus 10%	60 lbs.
Total	659 lbs.

659 lbs. @ $.095 per pound.................................$62.60

The torch cutting cost was determined in the following manner:

5/8" plate—180 feet @ $.10 per foot	$ 18.00
2" plate—228 feet @ $.23 per foot	52.44
1" plate—267 feet @ $.12 per foot	32.04
1 1/2" plate—143 feet @ $.17 per foot	24.31
1 1/4" plate— 26 feet @ $.15 per foot	3.90
3/8" plate—110 feet @ $.07 per foot	7.70
Total	$138.39

The labor cost of the bed is as follows:

760 feet of 1/4" rod—1 pass—16 ft. per hour	46 hrs.
890 feet of 3/8" rod—1 pass—12 ft. per hour	74 hrs.
Rough planing (before welding)	45 hrs.
Lineup	28 hrs.
Total	193 hrs.
193 hours @ $.90 per hour	$173.70
200% overhead	347.40
Total	$521.10

The complete cost would be:

Steel—42000 lbs. @ $2.25 cwt.	$ 945.00
Welding Rod	62.60
Stress Relieving—42,000 lbs. @ $.005 per pound	210.00
Torch Cutting	136.59
Bending Plates—(for spacers)	34.00
Labor	521.10
Cast Steel—(Oil Wells)—900 lbs. @ $.09 per pound	81.00
Total	$1,990.29

TABLE II—BILL OF MATERIAL OF STEEL FOR BED

No. of Plates	Designation on Bed	Size of Steel	Total Weight
17	Spacers	⅛ x 50 x 51	6828
1	Top of L.H. gib	2 x 11 x 768	4730
1	Bottom of L.H. gib	1 x 11 x 768	2365
2	45-degree gibs	2 x 9 x 768	7741
1	R.H. main plate	1 x 16 x 768	3440
1	L.H. main plate	1 x 18 x 768	3870
2	Floor plates	1½ x 8 x 768	5162
2	Column supports	1½ x 33 x 48	1491
2	Column supports	1 x 37 x 48	994
2	Column supports	2 x 20 x 48	1075
6	Column supports	1¼ x 14 x 37	1087
60	Floor support reinforcements	⅜ x 5 x 17	535
68	Gib supports (inside)	1 x 4 x 6	456
4	End plates for bolting	2 x 17 x 50	2040

TOTAL WEIGHT........................41,814 lbs.

Compared with the cast iron bed, we find a saving of 12,000 lbs. in weight, or 22%, and a saving of $494.71 in cost or approximately 20%. The saving in weight in the bed together with that saved in the table would realize the customer a distinct saving in shipping and foundation costs. Also the lighter members would be less likely to settle and distort the foundation, and in time, themselves over a long period of time.

Housings.—The function of the housings is to form a rigid member when bolted to the bed and the top brace; and also to insure a minimum of deflection against the force transmitted from the cutting tool and through the cross rail. A side view of the right hand housing is shown at left in Fig. 7. A cross-section taken at B-B, (upper left center, Fig. 7), shows that the general section is that of an "H" beam with a web thickness of 1½". The "H" beam section is ideal for minimum deflection, and rigidity is obtained by the 1½" x 6" webs completely around each opening.

To equal the above section for deflection in steel, a minimum web thickness of ⅝" could be used, and to gain a maximum in rigidity, the steel member should be of box type section. A side view of the steel member is shown at right in Fig. 7 and section B-B, at top right center in Fig. 7, shows the planned construction. Two ½" thick plates are used for the main members. This thickness gives us a deflection of 25%

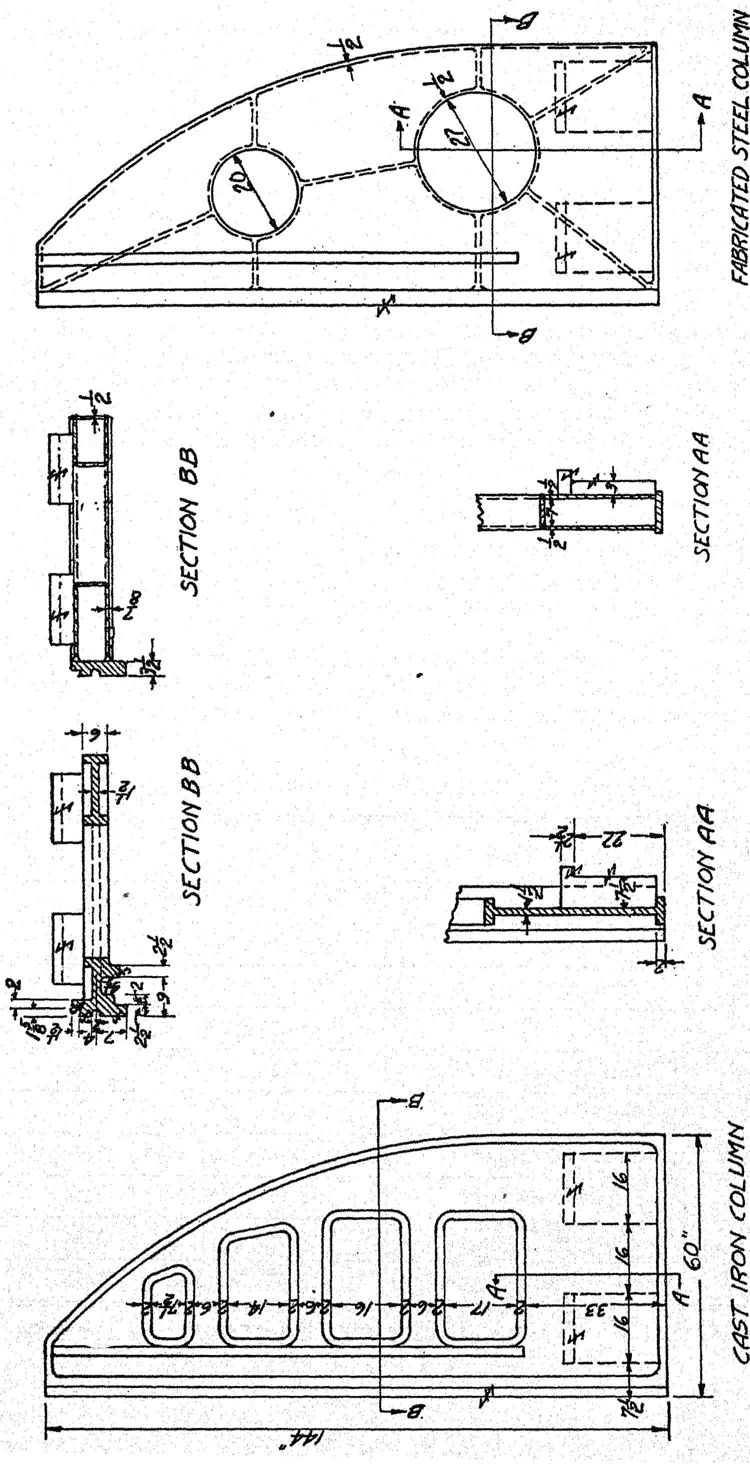


Fig. 7. Details of housing in cast iron and welded steel.

less than that of cast iron member gained by the difference of the modulus of elasticity between the two metals.

Referring back to the right hand view of Fig. 7, it will be seen that ½" plates were used to good advantage for a maximum box section for rigidity, and also to save a great deal of steel in the pads used to bolt the housings to the bed. The difference between the two designs can be seen at bottom left center in Fig. 7, for cast iron and bottom right center for steel. The finished pad has been reduced from 6¾" to 3". Also, in top left center Fig. 7 for cast iron and top right center for steel, the finish pad for the feeding rack has been reduced from 4½" high to ⅞" high.

Since all ribs would be contained between the two main plates, the finished product in steel would have a much smoother appearance than the cast iron member. Even though weighing considerably less, it would still have approximately 25% less deflection and would be definitely more rigid. A comparison of the two costs follows: The two cast iron housings weigh a total of 16,000 lbs.:

16,000 lbs. @ $.045 per pound	$720.00
Pattern Cost—(one-sixth actual cost)	50.00
Total Cost	$770.00

The bill of material of the steel housings is shown in Table III. The total weight in steel of the two housings is 12,678 lbs. The welding rod required was determined as follows:

TABLE III—BILL OF MATERIAL FOR HOUSINGS

No. of Plates	Designation on Housing	Size of Plate	Weight
1	Gibway	4 x 12 x 144	1935
1	Lower ring	½ x 7½ x 88	71
1	Upper ring	½ x 7½ x 66	53
1	Spacer	½ x 6⅞ x 222	216
1	Rack support, bar stock	1½ x 2 x 114	96
2	Finish pads for bed	2¼ x 6 x 16	120
2	Finish pads for bed	3¼ x 16 x 20	1128
1	Outside cover plate	½ x 7½ x 167	176
1	Floor plate	1 x 8 x 56	125
2	Main plates	½ x 56 x 144	2419

TOTAL WEIGHT (ONE HOUSING)........ 6,339 lbs.
TOTAL WEIGHT (TWO HOUSINGS)........12,678 lbs

177 feet of ¼″ rod—0.32 lbs. per foot		57 lbs.
43 feet of ⅜″ rod—0.40 lbs. per foot		17 lbs.
		74 lbs.
Plus 10%		8 lbs.
Total for Each Housing		82 lbs.
164 lbs. @ $.095	$15.58	

The torch cutting cost was determined as follows:

½″ plate—48 feet @ $.09 per foot	$ 4.32
1″ plate— 6 feet @ $.16 per foot	.96
2¼″ plate— 3½ feet @ $.43 per foot	1.51
3¼″ plate— 5 feet @ $.49 per foot	2.45
4″ plate—13 feet @ $.61 per foot	7.93
Total for Each Housing	$17.17

The labor cost follows:

177 feet of ¼″ rod—1 pass—16 feet per hour	11 hrs.
43 feet of ⅜″ rod—1 pass—12 feet per hour	4 hrs.
Rough planing before welding	14 hrs.
Lineup	12 hrs.
Total Labor for Each Housing	41 hrs.

41 hours @ $.90 per hour	$ 36.90
200% overhead	73.80
Total Labor Cost for Each Housing	$110.70
Total Labor Cost for Both Housings	$221.40

We can now determine the actual cost of the two steel housings.

Steel—12,678 lbs. @ $2.25 per cwt	$285.00
Welding rod	15.58
Stress relieving	78.40
Labor	221.40
Torch cutting	34.34
Total	$634.72

Comparing both designs, in steel construction, we have a saving of 3,322 lbs. or 20% in weight, and a saving of $165.00 or 20% in actual cost. Added to this, the steel housings would be more rigid, stronger and have a better appearance.

Arch.—The arch of a planer serves the primary purpose of holding the two housings rigidly. A box-type member with suitable ribs would be ideal but since a pattern of this kind would involve expensive core boxes, an "H" structure, or triangular shape, is usually used. Since weight is not important, the main members and ribs are usually made just heavy enough to be consistent with foundry practices.

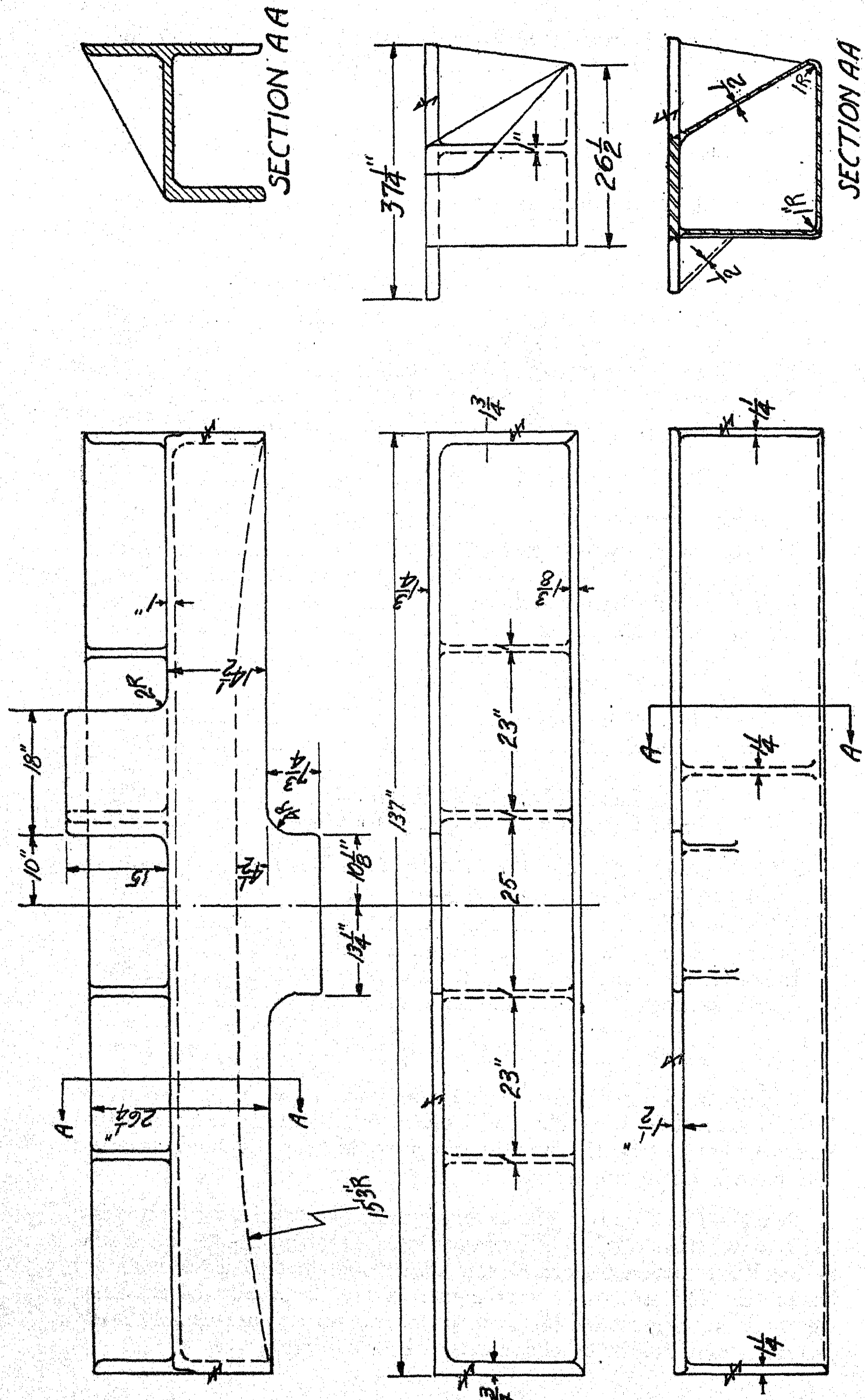


Fig. 8. Design of arch; above, cast iron, bottom welded steel.

The general design of the arch used on the planer in question is shown in Fig. 8. The two ends are finished for bolting to the housings, and the top is finished to receive pillow blocks and bearings of the elevating mechanism. At upper section A-A of Fig. 8, it will be seen that the arch is of "Z" type construction and braced with four 1" triangles. The entire member and its function on the planer lends itself readily to steel welded design. Weight is not essential and since a box type structure will support a maximum weight vertically, it is easily fabricated with a minimum amount of cutting and welding.

The bottom sketch of Fig. 8 shows the redesigned steel arch. In section A-A it will be seen that a ½" thick plate was bent in two places and used as the main member. Another plate 1¾" thick was used for the top and completed the box section. Two separate 1¾" thick plates were used for the pads and welded to the main top plate, and supported by suitable triangles. The reason for separate pieces is that it would have been uneconomical to cut it out of one piece with the top plate. There would, no doubt, be enough scrap around a steel shop for these items. The triangle supporting the pad in front is made of a ½" plate bent in two places. The steel arch will not only be more rigid, but also will present a better appearance, having well rounded corners and smooth surfaces. The cost of the steel member will be very reasonable.

A bill of material of the steel used is presented in Table IV. The cost for torch cutting is shown below:

½" plate—14 feet @ $.09 per foot	$1.26
1¾" plate—18 feet @ $.27 per foot	4.86
1¼" plate— 3 feet @ $.25 per foot	.75
1½" plate— 6½ feet @ $.29 per foot	1.89
Total	$8.76

The welding rod used was determined as follows:

9 feet of ¼" rod—0.32 lbs. per foot	3 lbs.
18 feet of ⅜" rod—0.43 lbs. per foot	8 lbs.
	11 lbs.
Plus 10%	2 lbs.
	13 lbs.
13 lbs. @ $.095 per pound	$1.24

The welding cost would be:

9 feet of ¼" rod—1 pass—16 feet per hour	1 hr.
18 feet of ⅜" rod—1 pass—12 feet per hour	1½ hrs.
Total	2½ hrs.

The labor cost would be as follows:

Welding	2½ hrs.
Lineup	4 hrs.
Total	6½ hrs.

$6\frac{1}{2}$ hours @ \$.90 per hour	\$ 5.85
200% overhead	11.70
Total	\$17.55

The complete cost of the steel member would be:

Labor	\$ 17.55
Torch cutting	8.76
Steel—3100 lbs. @ \$2.25 cwt.	68.75
Stress relieving—3100 lbs. @ \$.005 per pound	15.50
Bending main plate	8.00
Total Cost	\$118.56

Compared with this we have the cast iron arch which weighed a total of 3400 lbs.

3400 lbs. @ \$.045 per pound	\$153.00
Pattern Cost—(one-sixth actual cost)	16.00
Total Cost	\$169.00

TABLE IV—BILL OF MATERIAL OF ARCH

No. of Plates	Designation on Arch	Size of Plate	Weight
1	Main plate	½ x 68 x 134	1366
1	Top plate	1¾ x 14 x 134	984
2	End plates	1¼ x 20 x 24	360
1	Rear bracket plate	1¾ x 15 x 18	141
1	Front bracket plate	1¾ x 8 x 24	100
1	Rear triangle	1¼ x 14 x 18	94
1	Front triangle	½ x 10 x 28	42

TOTAL WEIGHT 3,087 lbs.

The saving in weight was 300 lbs. or 9%, and the saving in cost was \$50.44 or 30%.

Cross Rail.—The design of the cross rail of a planer requires particular attention. Even though the rest of the machine be perfect in design and construction, a weak cross rail will defeat the entire purpose. This member is subjected to forces in two directions; one directly proportional to the force of the cutting tool and one at right angles to it, which is amplified when dull tool bits are being used. These forces are uneven not only in magnitude, but also in their positions. Both cutting heads may be concentrated at the center which would load the rail to a maximum stress or one head may be at the center and one half-way between the center and either housing. A well designed rail must therefore have the following qualities:

(1) It must be unusually rigid to resist deflection in two directions.
(2) Since it is a simple beam structure in application, it must be of such shape as to resist any and all forces without advantage of bracing to other members.

(3) It must retain its alignment without distortion or set for the life of the machine. The alignment must be maintained against accidental shocks from hitting solid stops or job setups.

The general construction of the cast iron rail is shown in Fig. 9. Section A-A shows the design of each end, and section B-B illustrates the box type construction of the center. The main members are 1¾″ thick, and the center rib tapers from 2¼″ at top and bottom to 1¼″ at the center. It is well braced by three main ribs, each 1⅛″ thick, and nine 1″ thick triangles. The design is good, both for rigidity and shock resistance. One major shortcoming in cast construction, however, is the cost of a pattern. This is due to the unusual amount of core box work involved.

Redesigning for steel welded construction is fairly simple. The structure can be easily duplicated for shape, and since it can be made much lighter, additional bracing can be added at very little cost. The steel welded cross rail is shown in Fig. 10.

From section A-A and section B-B can be seen that the thickness of the main members is reduced from 1¾″ in cast iron to 1″ in steel. This reduction not only means a saving of 60% in weight of these members but deflection is still reduced by approximately 30%. Even though equal deflection with the cast iron rail could have been accomplished by ¾″ plates, it would be unwise to sacrifice the added rigidity. The main bracing was increased from three ribs to five, and the thickness reduced from 1⅛″ to 1″. The total thickness of the cast iron ribs is 3⅜″ while the five steel ribs total 5″. Therefore, deflection in this direction, which is the main line of the force of the cutting tool was reduced by approximately 350%. Moreover, as will be noticed from Fig. 10, these main ribs extend from the back plate to the gibways. This provides added rigidity. The top, bottom and back plates were combined into one bent member, thereby saving cutting, welding and lining up time. The gibways are made of two 4″ thick plates having the same dimensions as the cast iron rail. The lower gibway will, of course, have to be rough planed before welding to save subsequent machining time.

Comparing the costs of the two methods of construction, we find that the cast iron rail weighs a total of 9000 lbs. in the rough:

9000 lbs. @ \$.045 per pound	\$405.00
Pattern Cost (one-sixth of actual)	30.00
Total Cost	\$435.00

The bill of material of the steel used in the welded cross rail is shown in Table V. The steel used amounted to 6900 lbs.

The welding rod required was determined as follows:

140 feet of ¼″ rod—0.32 lbs. per foot	45 lbs.
104 feet of ⅜″ rod—0.40 lbs. per foot	42 lbs.
	87 lbs.
Plus 10%	9 lbs.
Total	96 lbs.

96 lbs. @ \$.095 per pound \$9.12

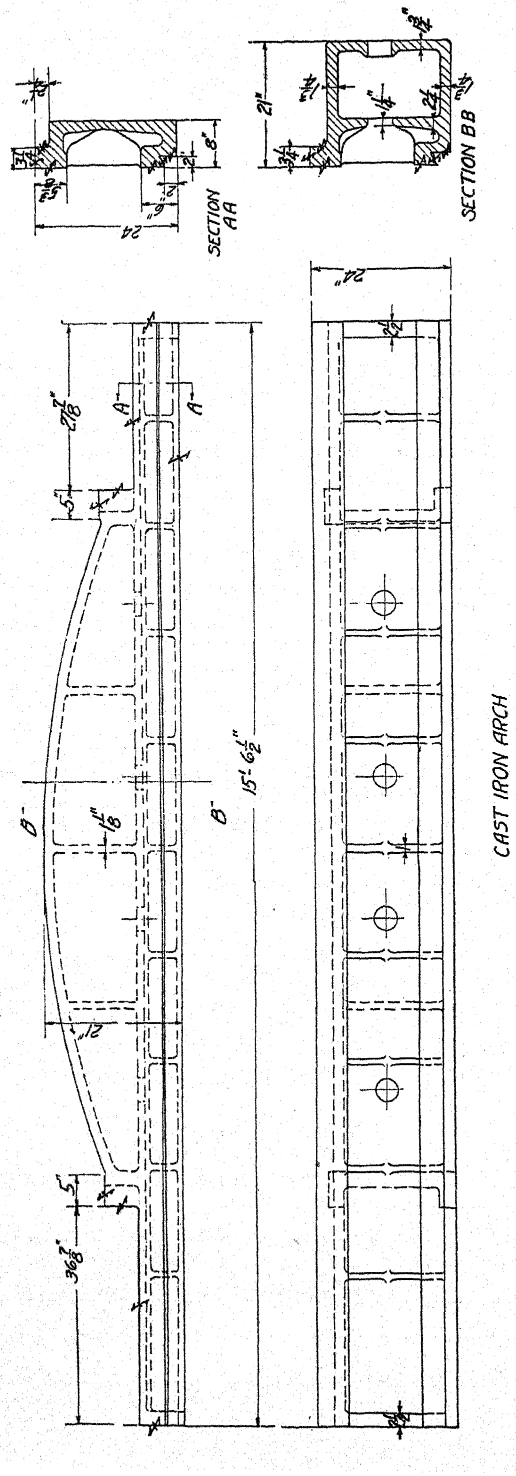


Fig. 9. Cast iron arch.

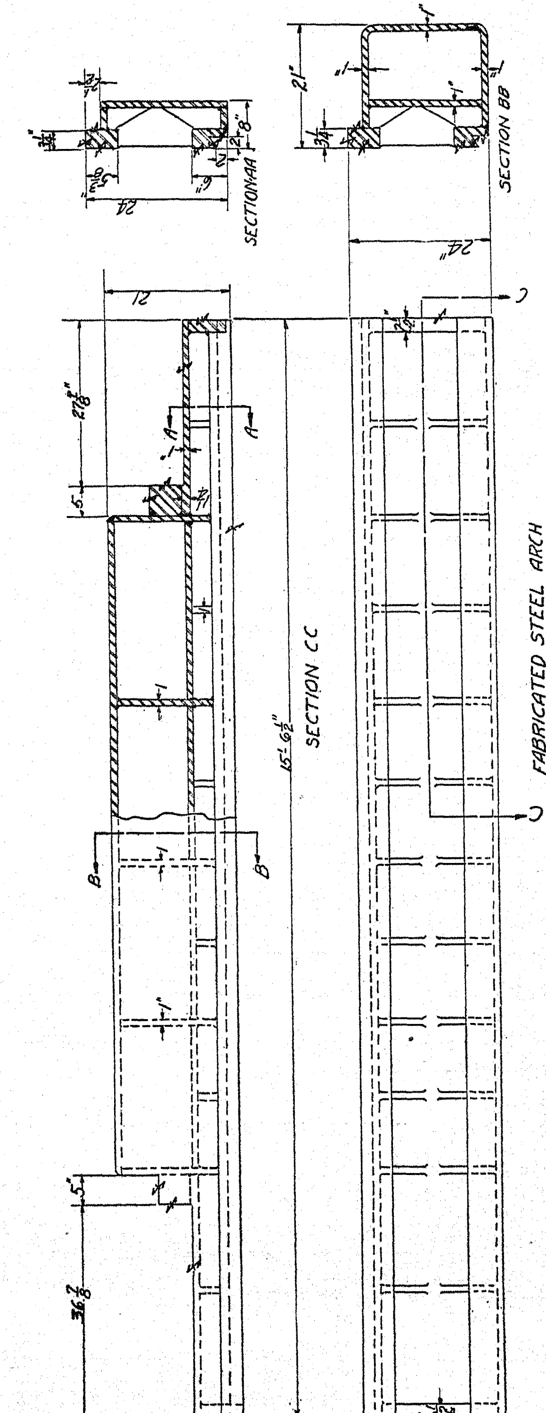


Fig. 10. Arc welded steel arch.

TABLE V—BILL OF MATERIAL OF CROSS RAIL

No. of Plates	Designation on Cross Rail	Size of Plate	Weight
1	Back plate	1 x 56 x 120	2025
2	Rear end pads	1¼ x 20 x 32	480
2	Outside main ribs	1 x 20 x 32	375
1	Center main rib	1 x 20 x 32	318
1	Top rail	4 x 6 x 187	1338
1	Bottom rail	4 x 6½ x 187	1451
2	End pieces (between rails)	3 x 7 x 20	252
4	Rear bolting pads	3 x 3 x 5½	57
5	Main cross ribs	1 x 17 x 20	510
6	Triangles	1 x 5 x 8	72

TOTAL WEIGHT........................6,878 lbs.

The torch cutting cost was determined as follows:

1″ plate—63 feet @ $.12 per foot	$ 7.56
1¼″ plate— 9 feet @ $.20 per foot	1.80
3″ plate—16 feet @ $.45 per foot	7.20
4″ plate—32 feet @ $.46 per foot	14.72
Total	$31.28

The labor cost for fabricating is as follows:

140 feet of ¼″ rod—1 pass —16 feet per hour	9 hrs.
104 feet of ⅜″ rod—2 passes— 6 feet per hour	18 hrs.
Rough planing (gibways)	7 hrs.
Lineup	8 hrs.
Total	42 hrs.

42 hours @ $.90 per hour	$ 37.80
200% overhead	75.60
Total	$113.40

A complete cost would be:

Steel—6900 lbs. @ $2.25 cwt.	$155.25
Welding rod	9.12
Torch cutting	31.28
Labor	113.40
Stress relieving—6900 lbs. @ $.005 per pound	34.50
Total	$343.55

Comparing the two designs we have a saving of \$91.45 or 21% of the welded steel over the cast iron, and a saving of 2100 lbs. or 23% in weight. In spite of this reduction in weight, as has been demonstrated, the steel rail would be more rigid and have 350% less deflection under equal loads than the cast iron rail.

Summary.—The total weight of the cast iron members which we have considered was 134,400 lbs. The steel members would weigh 98,900 lbs. This would mean a saving of 35,500 lbs. or 26%.

The cost of the cast iron members was \$6286.00, and that of the steel welded structures would have been \$4925.05 which would mean a saving of \$1360.95 or 21%.

Added to the advantages of reduced weights and costs is another which would be a decided selling feature. It is the advantage that would not confine the customer's requirements to specific dimensions. If another foot or two was required between housings, or a little more height under the cross rail, both could be furnished at very little actual cost and certainly at no added engineering expense.

The cost of the steel members included charges for stress relieving. This cost was based on commercial estimates. Stress relieving not only eliminates the stresses set up in welding, but also relieves any strains set up in the actual rolling of the plates themselves. Consequently, all steel members would be entirely free of internal strains and therefore would hold their machined alignment indefinitely. The cast iron members, being of unequal cross-section and unusually heavy, would, no doubt, have internal casting strains that would not appear until after machining. This type of machine is of such proportion that no casting for it would be carried in stock, and consequently the members would not enjoy any appreciable seasoning period.

As a final summary the advantage of manufacturing a planer of welded steel members would be as follows:

(1) Reduced manufacturing costs, and consequently greater marketing possibilities at no sacrifice of profit.

(2) Reduced weights, which mean economical handling, lower shipping costs and less expensive foundations.

(3) Greater freedom of design with regard to new ideas and improvements. Engineers would not be confined to existing expensive patterns.

(4) Greater sales possibilities with regard to customer's requirements. Extended dimensions in width between housings, and greater height under rail could be offered at no additional cost.

(5) Greater sales possibilities with regard to lower power consumption. Lighter tables would mean less horsepower requirements and greater operating speeds.

(6) Shorter deliveries, since most planer members are of such proportions as to tax almost any foundry's capacities.

(7) On the basis of approximately \$6,000,000 worth of planers sold in a normal year, the industry would realize a saving of at least \$1,200,000 in purchasing power alone. Added to this would of course be the continual saving of power, and the initial saving of freight and foundation costs.

Chapter III—The Evolution of "Contour Machining"

By LEIGHTON A. WILKIE,
President, Continental Machine Specialties Co., Minneapolis, Minn.

This entry in the James F. Lincoln Arc Welding Foundation program aims to offer a different type of presentation than the usual article on advantages in welded fabrication. Articles on this subject have well covered the advantages which include cost reduction, faster production, greater serviceability, lighter weight, improved appearance in the finished product, etc. It was these advantages that motivated our adoption of the welded fabrication method. The manner in which these advantages has worked out in our product is so obvious that it does not strictly make news. Beyond these basic accomplishments there is a romantic story. It is the story of the rapid evolution of a product and the important part that arc welding played in this evolution.

Origin of the Band Saw.—One hundred and thirty years ago William Newberry of London invented the original band saw. However, it did not become practical until thirty-eight years later when a means was developed for making a suitable joint in the band saw. In 1846 a French woman named Mlle. Crepin patented this means of welding the saw which she had developed. This resulted in intensive perfection of band sawing so that by the time of the World's Fair in Chicago in 1898 the band saw displays were among the most popular exhibits for the lumbering industry.

Metal-cutting band saws were subsequently developed which generally used saws about 1″ wide. Six years ago the advent of new alloys such as chromium, molybdenum, etc., made it possible to use a very narrow metal-cutting saw. These tough, slender saws had the capacity of cutting through thick sections of steel. They possessed long life and were extremely efficient.

The general classification of narrow-blade band saws takes in those from ⅜″ wide down to $\frac{1}{16}$″ wide, all generally .025″ thick. This range of widths included a great variety of tooth constructions in order to cut all types of material. For example, the teeth varied from 6 to 32 per inch. There are three sets—wave, straight and raker. There are also three tempers. These several variables naturally worked out into a wide variety of saws. Less than six years ago nothing was known of the technique of operating these saws nor of a machine tool on which they could be used. Upon the ability of these narrow saws was built an entirely new machine tool which today amounts to a new cutting process. This new cutting process is revolutionizing machine shop practice throughout the world. The machine is in use in 90% of the aircraft factories in the world. Three to thirty machines are used in plants like General Electric, General Motors, Ford, International Harvester Company, International Business Machines, Westinghouse, etc., and in hundreds of little tool shops everywhere.

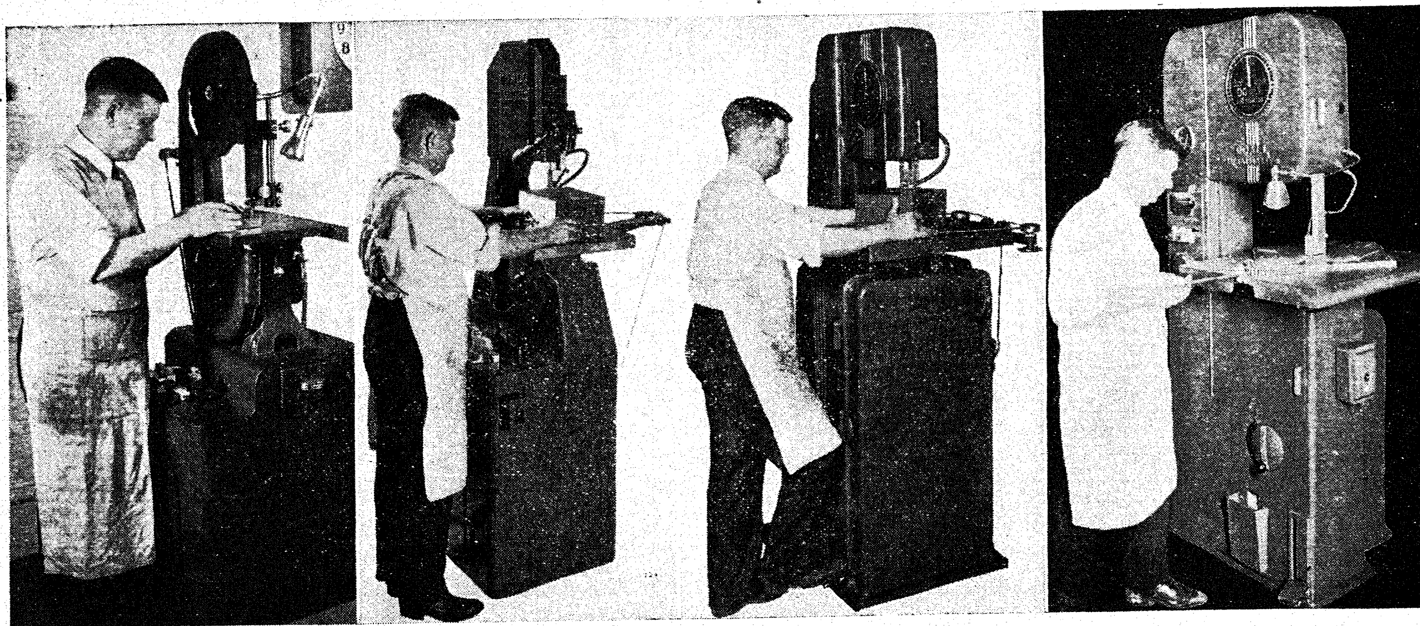


Fig. 1. Evolution of "contour machining". Left—the original model; next, second model; next, third model; right, latest model, in all-welded steel construction.

The phenomenal and rapid evolution within six years of the machine tool and the technique is one of the most interesting chapters in the history of metal cutting. Six years ago our development started by acquiring a variety of the narrowest saws then available for metal cutting from various manufacturers. These were used on a wood cutting band saw which was converted to run at slow speed and had several refinements necessary for handling the metal cutting blades. On to this machine was attached a welding device so that we could join bands right at the machine for internal continuous sawing—a new metal-cutting art. This experimental machine was put to work sawing out dies and punches in our tool room. Because this eliminated the cumbersome and costly method of drilling a row of holes, hammering out the slug and filing the drill marks off, the sawing idea took so well that toolmakers were more than enthusiastic for it. In eliminating what they called the old "blacksmith" method, they felt it had eliminated the most menial task of their art and placed the operation on a high plane.

We recognized that the possibilities for this sawing process were enormous and we immediately prepared to manufacture and sell the machine. We also developed a continuous cutting file band which could be used on the same machine so that when a toolmaker had the die sawed out he could file it to finish right at the same machine. This idea was stimulated by the fact that the old reciprocating type of saw was equipped to operate a reciprocal file. It had become generally established that the filing followed in such close sequence after the sawing that the two operations should be done on the same machine. All through this development we were experimentally cutting every metal and material. We saw that while other cutting processes were limited to cutting certain classes of metals this machine, with its new saws and files, could cut all metals and, in fact, all materials. For example, the flame cutting method was capable of cutting only low carbon steels; it was not able to cut aluminum, brass, bronze, etc., much less bakelite, fiber, etc. We saw that the saws were not only more versatile in their cutting ability but left an even, machined surface. We saw that the low cost of these saws and their extremely fast cutting ability had enormous possibilities. Because of these fundamentals our development of the technique for operating all of the types of saws was pushed on. We compiled our data in an elaborate Handbook which is the world's basis for all authority on the art. One section of this is devoted to the relationship between arc welding and contour sawing in jigs and fixtures. American manufacturers are the only ones who produce these narrow saws although narrow-blade machines have recently been developed in certain foreign countries, particularly Germany. They obtain their saws from the United States. We received no contributions from any quarter in pioneering this art. The progress we made was developed in such rapid strides that competition lagged.

First Model.—In getting started, our only major mistake was in presuming that these narrow saws could be operated by a light machine. Because they were themselves light, we thought a light machine would be sufficient. Just the reverse proved to be true. Before we had

a hundred machines on the market we realized that the light-weight machine was fundamentally wrong for these narrow saws. It takes a husky milling machine to operate even a tiny end mill. By this same process of reasoning the contour sawing machine had to be rugged. Our first machine sold for approximately $500 and weighed approximately 500 pounds. It was called the Model ABW.

Second Model.—Our next machine was designed with a very rugged "C" frame. This yoke construction followed the general idea of all previous band saws in that it was a goose neck, hollow frame. We made the casting extra rugged out of nickel iron. We were careful to season it before machining. However, even with these precautions we had occasional trouble from warpage. To support this frame we mounted the machine on an arc welded base. This base formed a cabinet which contained the variable speed transmission, power feed mechanism, motors, air pump for chip disposal, etc. It is interesting to note that while the upper and lower wheels in this model were well guarded, they were not fully enclosed. This was to follow in our plan for a truly functional design. The model sold for approximately $800 and weighed approximately 800 pounds. It was completely successful but was rather expensive to produce. We felt that by re-designing it we could "streamline" it to more pleasing styling and at the same time reduce its operations. We also felt that even greater ruggedness was desirable.

Third Model.—In building the third model, we adopted the principle of using the frame of the machine as the housing. Prior to this, all band saws were constructed on the principle of having a "C" shaped frame on to which the upper and lower wheel were mounted. We learned that we could make this frame become a housing for the machine and container for the upper and lower wheels. This revolutionary idea developed into a machine which was far more practical than the former type of construction. It permitted straight-line design. It permitted "building in" so that the entire outside of the machine was smooth and clean of line.

When we announced this machine to the trade we received very high tribute from many sources for its pleasing and modern design. The machine was made of seasoned castings. It weighed 1250 pounds and sold for $1250. This price was rather high for the small shop. While we sold a great many to the larger shops, we were losing ground in the small die shop because they were unable to pay the price necessary to buy this super tool room machine. We saw the necessity of producing a machine at a lower price. This brought us to arc welded construction.

The Final Model.—Using the same styling as our previous machine, we produced a new model entirely of arc welded construction. This new model employed many revolutionary features. It enabled us to substantially reduce the price and at the same time give the customer a machine of much greater capacity. Our second model, at $800 had only a 12″ throat and $7\frac{1}{2}$″ work thickness capacity. Our third model, at $1250, had a 14″ throat and 8″ work thickness capacity. Now comes the final model with a 16″ throat and 8″ work thickness capacity

for only \$800. Its 950-pound weight is 300 pounds less than the preceding machine, yet it has a 2″ greater throat capacity. This remarkable saving resulted directly and entirely from arc welded construction. Our fabricating problems were greatly simplified and production costs dropped below the cost of producing the original model. It is not simple to express the saving in percentage. However, we are safe in saying that our program of redesign, employing arc welded construction, resulted in savings of from 20% to 40%.

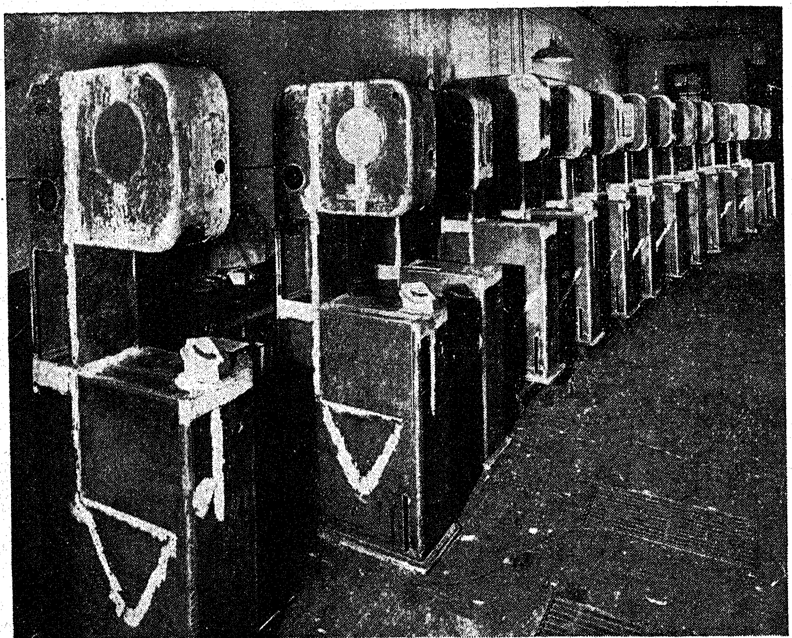


Fig. 2. A production line of arc welded housings.

One Piece Construction.—The housing of the new model is entirely arc welded, and except for the transmission cover is entirely in one piece. This, in itself, eliminated several operations over the previous model which was made of castings. The elimination of expensive patterns was a consideration in our employing welded steel. We also found that the elimination of pattern changes and the resultant delays in production were of prime importance. After the first welded steel housing was completed, we found it necessary to change the transmission. This meant a slight alteration in the subsequent welded housings, but would have meant a major pattern change and considerable delay had the construction been of cast iron. The fact that the welded steel housings are more uniform, (See Fig. 2), made it easy to build in sub-assemblies. The clean straight lines of design were made even simpler with this construction than with the castings. It was also easier to fill and paint the steel plate than the castings and a smoother, better finish

was obtained. The arc welded construction permitted us to reach our final goal in functional design which we were constantly striving for.

Better Appearance.—By referring to the photographs in Fig. 1, which present the several models in the evolution of this machine, the improvement in appearance with each successive model is very apparent. The more steel plate construction is used, the better the appearance in each succeeding model. The final model is built entirely from standard steel plates joined by arc welding. Yet the finished housing appears as an integral piece of metal with contours as if it were molded or drawn in a die. An examination of Fig. 3 which shows the bare frame housing indicates how the complicated inner structures have been molded in as part of this intricate graceful shaping.

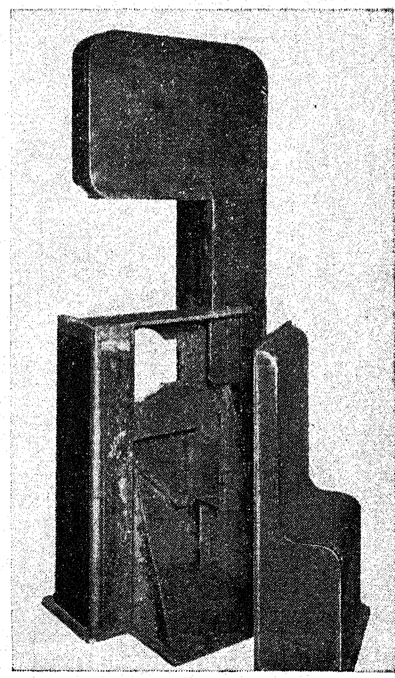


Fig. 3. Arc welded housing, showing inner construction.

April 29, 1938, we introduced the new model at the Twin City Welding Show. Crowds thronged in our booth to see the machine that could "saw curves internally through thick steel". Many a comment was heard, "Why, I can't imagine that it's welded steel; it's so streamlined". Or "I thought it was a heavy cast iron machine. It's impressive mass and molded appearance fooled me". Yet we intended no deception when we designed this machine. Actually, it would be a difficult task to reproduce it in cast iron.

No Machining.—In this new model we have developed an ingenious fabricating method. This method eliminates the necessity of doing any machining whatsoever on the arc welded frame. Instead, we premachine plates which are drilled and tapped and ground so that they may become anchor plates for sub-assemblies that are to be mounted on the machine. Then, we arc weld these anchor plates on to the housing. Our method of welding these anchor plates in position is to first bolt the anchor plates on to a rigid welded "I" beam jig. This jig holds the anchor plates in exactly the right position on the frame while they are being arc welded. When the jig is removed, the unit has machined surfaces which line up with each other and are in exactly the right position for assembling the machine.

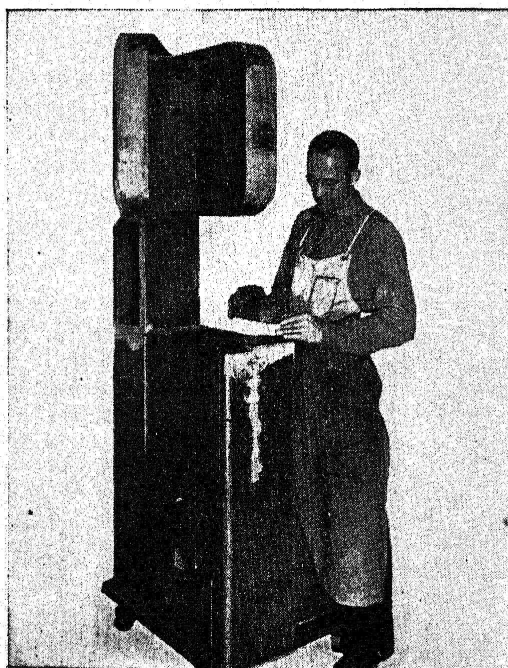


Fig. 4. Welded steel housing with pre-machined anchor plates and table trunnion about to be mounted.

The enormous advantages in this positive pre-machined, welded anchor plate construction are more apparent when it is realized that the alignment of the two drive wheels and the two saw guides must be exact. But for this new method, expensive machining operations would be required at these four points on the entire housing. Of course it is necessary to scrape in the ground surfaces of the anchor plates, but this operation takes but a short time because, actually, the plate positions are held to a tolerance of .001″. Fig. 4 best illustrates how three of these anchor plates are in position in the upper half of the machine and how a trunnion cradle is about to be clamped in position

on one of these anchor plates. This trunnion cradle carries the work table. The sum total of the savings derived from arc welding construction over the use of castings in our previous fabricating methods have been great. In fact, it permits us now to tap export fields that we were not able to invade because of the weight and price of our previous models. The value that the customer now receives is much greater than with any previous model.

Arc Welded Construction Exclusively Used.—In addition to the new model we also produce a sister machine. This machine has the same throat capacity but allows for 10″ of work thickness. It has an even higher quality of construction and a wider range in all of its functions. Quiet, vibrationless operation under any load, characterizes these new machines.

Our largest machine has 30″ throat depth. The weight of this machine in cast iron would be prohibitive. It is constructed of an arc welded housing having a cast upper structure. At this writing, we are commencing the redesign of this model to all-welded steel construction, thus unifying our line of machines to identical construction methods and simplifying our parts inventory.

It is interesting to note that for a special extra large machine which a customer required, we built it up entirely of arc welded construction. This permitted us to make just the one machine at an economical price because of the elimination of pattern cost and expensive machining cost for assembling castings.

It is interesting to observe that we have launched this new line of arc welded machines during the current depression. Because of the lower price and larger capacity, these new models are actually solving an acute problem for us in getting a profitable volume of business. There is no higher tribute to arc welded construction in machine tools than the complete adoption of that method in the evolution of the "Doall" machine.

Chapter IV—Welded Riveting Machine

By John M. Baxter,
Chief mechanical engineer, Sir William Arrol & Co., Ltd., Glasgow, Scotland.

A welded riveting machine may seem to be a contradiction, but we can claim, without contradiction, that it is more reliable than the conventional construction in cast steel, and further, that it costs less.

In 1929 we reached an acute stage in our endeavours to obtain sound steel castings for hydraulic riveting machines, one of our standard products. One of the machine frames, a large steel casting which, to all appearances was perfectly sound, showed a hair crack on the application of load. We cut out the section where the crack was, and you may imagine our distress and consternation when we found that only about half of the cross sectional area was sound, and this, at the point of highest stress!

We do not make castings ourselves, and have, therefore, to purchase them from the steel founders. In view of the serious defect mentioned above, we had a conference with a leading metallurgist and a representative of an important steel foundry in order to see what could be done to improve matters. A revised specification was drawn up for the steel material, but one alarming fact still remained: although the founders could guarantee that the metal would conform to the specified physical requirements and chemical analysis, they could not guarantee that any casting would be 100% sound. The position was, therefore, very unsatisfactory, but at that time we had no alternative but to carry on with the revised specification for the cast steel material.

In 1930 we became interested in fabrication by welding, and gradually changed over from castings to weldings in the case of brackets and similar details. In the following year we decided to make for ourselves a welded riveting machine, and as the stresses in this machine are fairly high and repeated two to three times every minute we were of the opinion that it would be a real test for this type of construction. This machine proved to be entirely satisfactory, and in 1934 we made for ourselves another welded machine of a different type. This machine was also satisfactory, and both machines have been in constant use since manufacture. At the present time the second machine forms one of the exhibits at the Empire Exhibition, Glasgow. Since 1934, practically all riveting machines we have manufactured have been of the welded type.

The welded machine which I describe below, and which is now under construction, was specially designed for riveting, in a restricted space, the bulkhead frames of a ship's hull. Our clients were inclined to favour the cast steel construction, but we ourselves, in view of our experience, wished to put forward a welded construction. Both types of machine were, therefore, very carefully investigated and alternative estimates prepared. The welded design was finally accepted and ordered by our clients.

General Description.—The riveting machine, which is the subject of this paper, consists essentially of two hinged frames or levers terminating at the riveting dies or snaps on the "gap" side and at the power unit or jack on the other side. Hydraulic pressure is applied to the ram of the jack to give the necessary force on the snaps for closing the rivet—in the present case, 90,000 lbs. The jack incorporates a constant pressure drawback anulus, so that, when the main ram is exhausted the riveting snaps are opened, allowing the machine to be moved to the next rivet. Hangers are provided so that the machine can operate in any plane as required.

Cast Steel Machine.—Fig. 1 shows the cast steel construction which was put forward. It will be noted that the nose of the machine is specially narrow to allow of riveting in a confined space, and that the overall width, 4′4″, is also restricted for a similar reason. The gap, 7′0″, is about a maximum for this type of machine.

The usual construction for the ram is a solid forging or hollow casting. In the case under review, a solid ram was proposed to assist in balancing the heavy front section without undue lengthening of the back arm.

The weight of the cast steel machine worked out at 9,500 lbs., and the estimated cost £319.16. Od., ($1554.23), as detailed below. The time for delivery, which was controlled by the foundry, was five months.

COSTS OF CAST STEEL RIVETING MACHINE

Cast steel in frames, including cylinder 8,600 lbs. per quotation from founders—January 1938	£191. 5. 0.=	$ 929.47
Mild steel forging for ram 760 lbs., per quotation —January 1938	8. 10. 0.=	41.31
Patterns for frames, per quotation from founders—January 1938	50. 0. 0.=	243.00
Labour costs per works' estimate	33. 0. 0.=	160.38
	£282. 15. 0.=	$1374.16
Special cast iron in footstep	1. 17. 6.=	9.11
Gunmetal fittings	4. 3. 0.=	20.17
Special bronze bushes for main hinge	2. 16. 0.=	13.61
Mild steel material for hanger and other details	5. 4. 9.=	25.45
Special steel for bolster, snap holders, hinge pin and snaps	4. 10. 3.=	21.93
Leather packing rings	1. 16. 0.=	8.75
Operating valve, piping and connections	6. 13. 6.=	60.87
Pattern for cast iron and gunmetal fittings per works' estimate	5. 0. 0.=	24.30
Labour costs per works' estimate	5. 0. 0.=	24.30
	37. 1. 0.=	180.06
Total	£319. 16. 0.=	$1554.23

Welded Machine.—Fig. 2 shows the welded construction. By adopting a special design for the nose end of the frame, we were able to give effect to the narrow width which was a special feature of the cast steel machine. Also, by the use of high tensile steel plates,

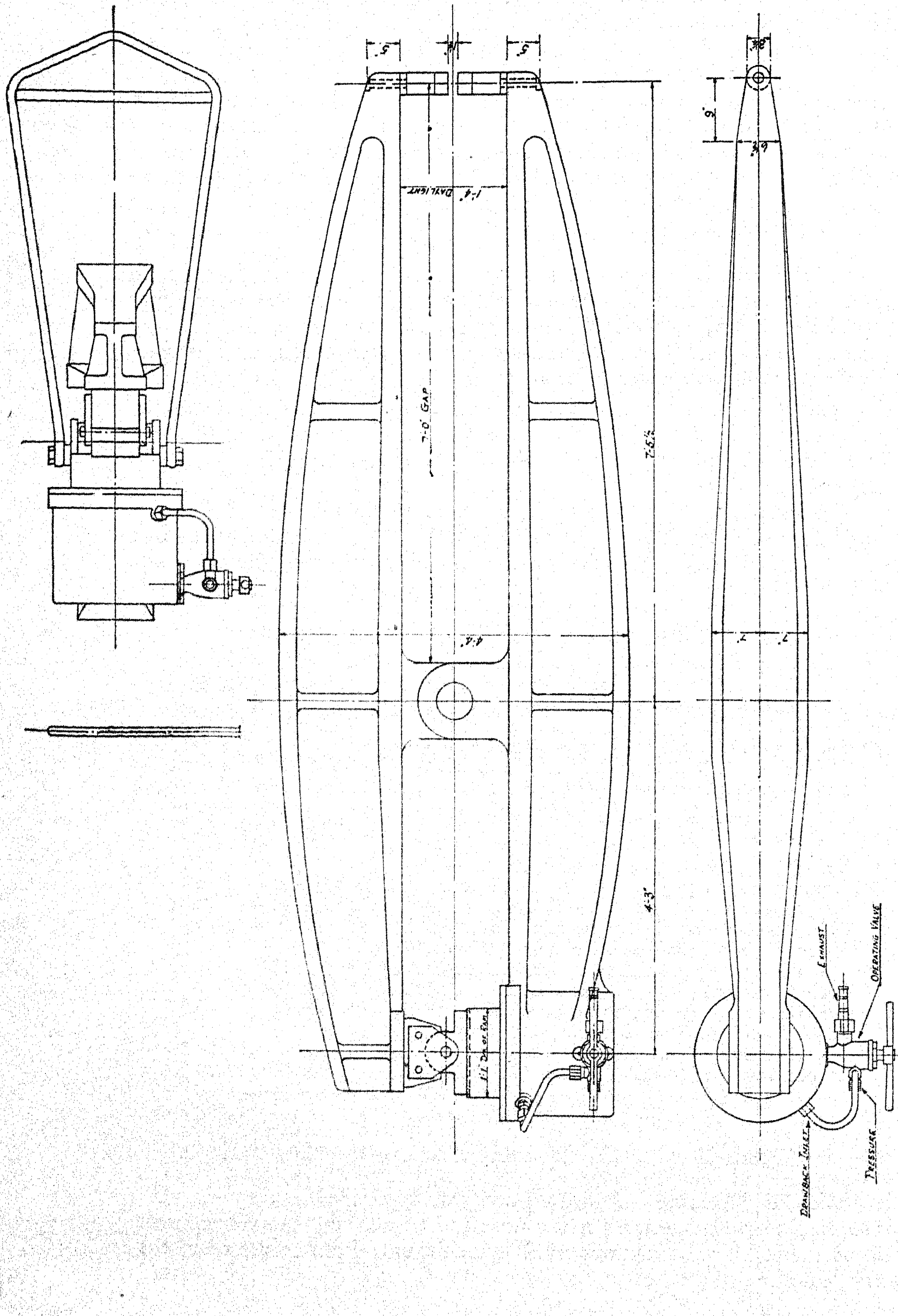


Fig. 1. Design of riveting machine for cast steel construction.

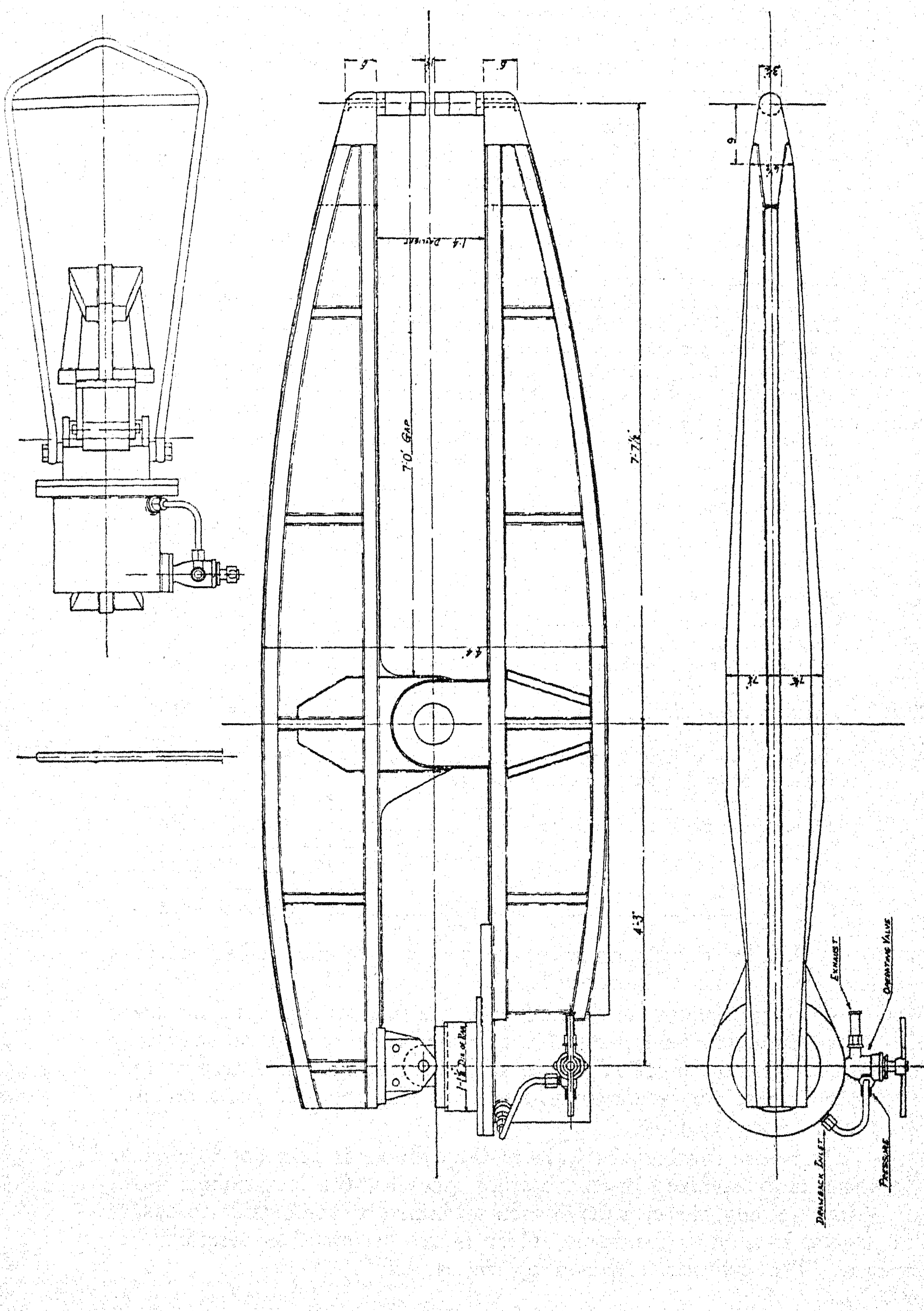


Fig. 2. Design of riveting machine for arc welded construction.

(83,000/96,000 lbs. per square inch ultimate tensile), the overall width of 4′4″ for the frame was possible without making the machine unduly heavy. As the front arm of the welded machine was lighter than in the cast steel type, the ram of the jack was made of hollow welded construction.

The estimated weight of the welded machine is 8,400 lbs., and the cost £185.16. 0d., ($902.99), as detailed below. In the case of the welded machine we were able to quote a delivery of 3½ months.

COSTS OF ARC WELDED RIVETING MACHINE

High tensile steel plates in frames, 8,200 lbs., per quotation from steelworks—January 1938	£ 53. 5. 0.=	$ 258.79
Mild steel plates for cylinder and other details, 1,730 lbs., per quotation from steelworks—January 1938	9. 6. 0.=	45.20
Mild steel plates for ram, 615 lbs., per quotation from steelworks, January 1938	3. 17. 0.=	18.71
Steel material for special nose pieces 475 lbs.	3. 7. 0.=	16.28
Electrodes and oxygen for torch-cutting—per works' estimate	8. 0. 0.=	38.88
Labour costs per works' estimate	71. 0. 0.=	345.06
	£148. 15. 0.=	720.49
Special cast iron in footstep	1. 17. 6.=	9.11
Gunmetal fittings	4. 3. 0.=	26.73
Special bronze bushes for main hinge	2. 16. 0.=	13.60
Mild steel material for hanger and other details	5. 4. 9.=	25.45
Special steel for bolster, snap holders, hinge pin and snaps	4. 10. 3.=	21.93
Leather packing rings	1. 16. 0.=	8.75
Operating valve, piping and connections	6. 13. 6.=	32.44
Pattern for cast iron and gunmetal fittings per works' estimate	5. 0. 0.=	24.30
Labour costs per works' estimate	5. 0. 0.=	24.30
	37. 1.0.=	230.06
Total	£185. 16. 0.=	$ 902.99

A detailed description will now be given of the welded machine and the methods of fabrication.

Two large plates are ordered from the steel works, and from these plates the component parts of the frames are torch-cut, as shown by Fig. 3. The torch-cut edges are sufficiently straight and true to butt close enough for welding without machining, but the parts are flattened before assembly.

The plate forming the walls of the cylinder is bent hot to circular form, and machined on the butting faces for the longitudinal weld. After welding, the cylinder is then machined on the outside to ensure a good butt on to the frame, which is also machined as described below. The cylinder is shown by Fig. 4, left.

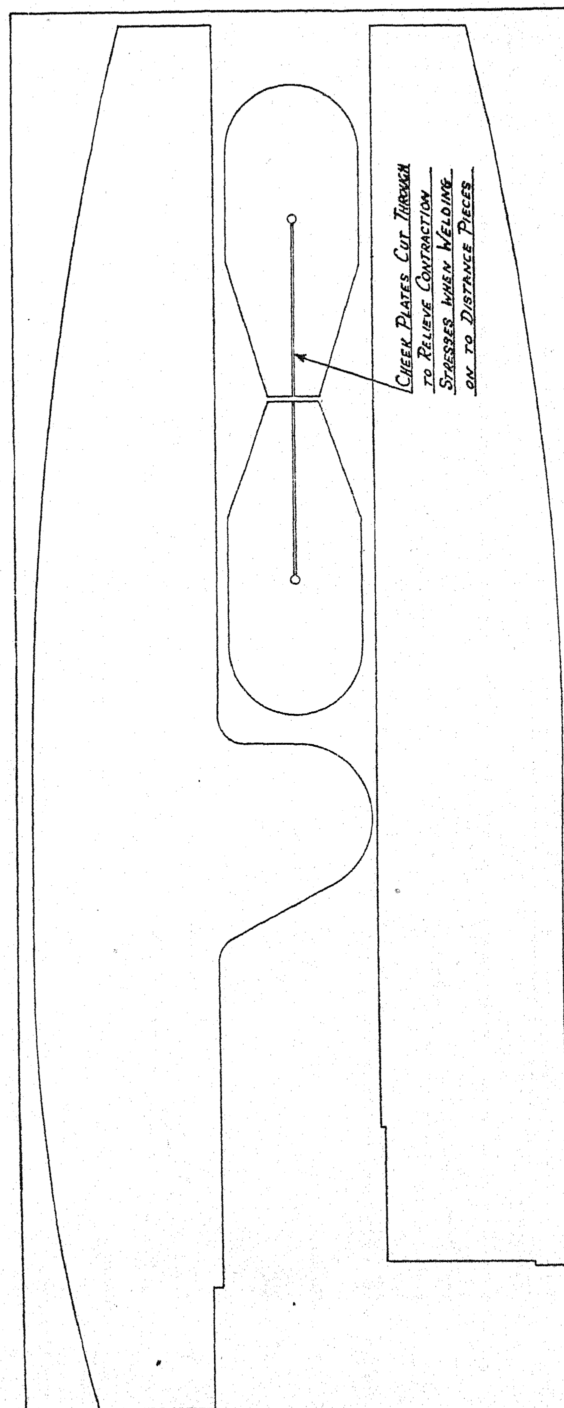


Fig. 3. Component parts of riveting machine frames for cutting. See also page 999a.

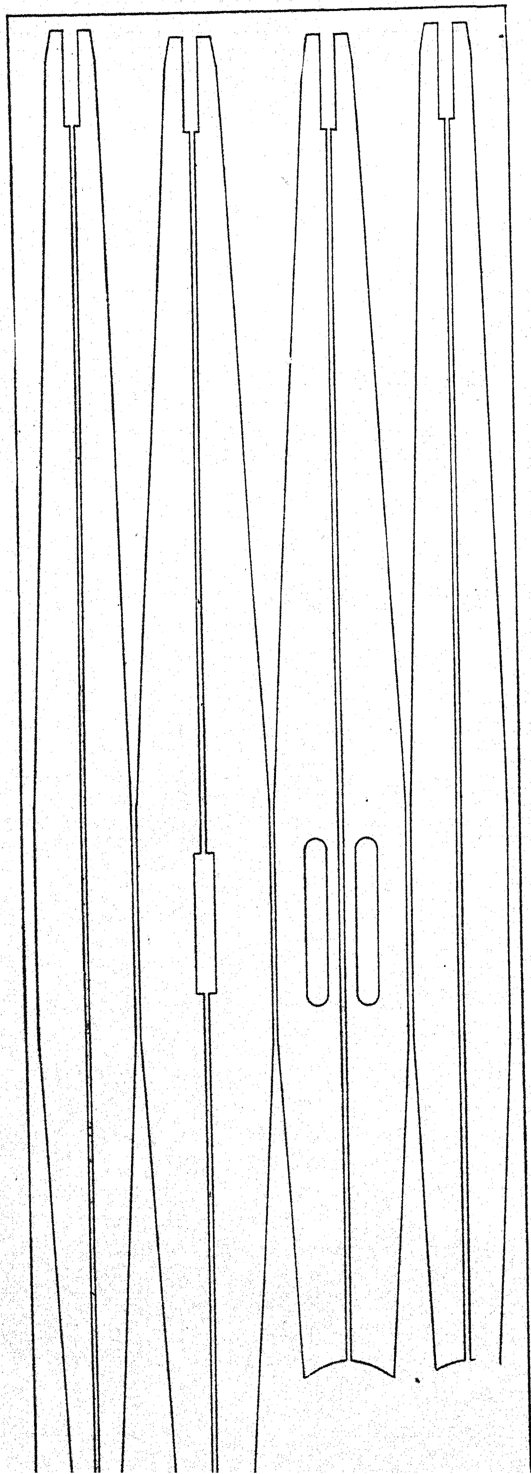
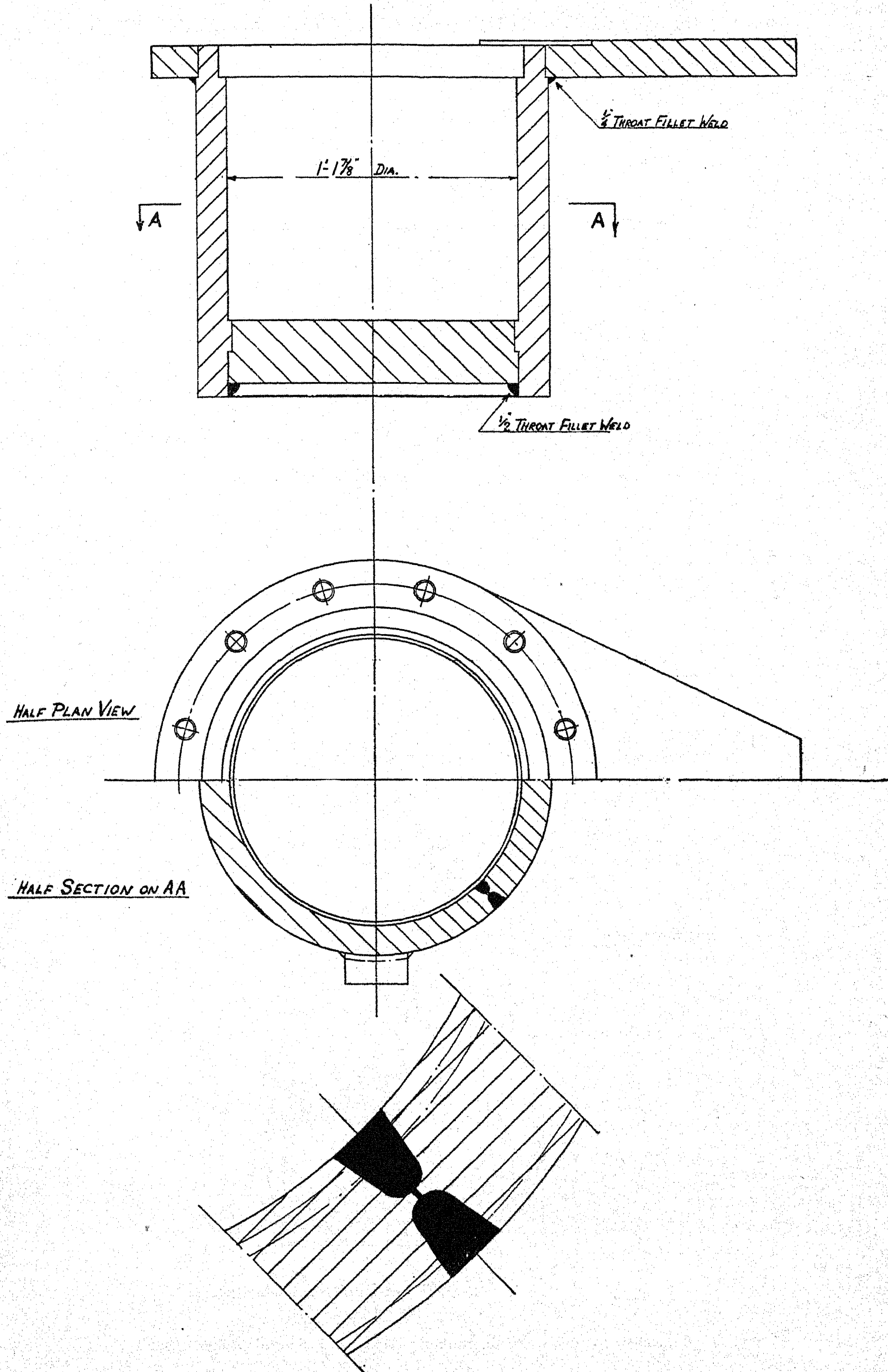


Fig. 3. Component parts of riveting machine frames for cutting. See also page 999.


1/4" Throat Fillet Weld
1'-1 7/8" Dia.
A
A
1/2" Throat Fillet Weld
Half Plan View
Half Section on AA

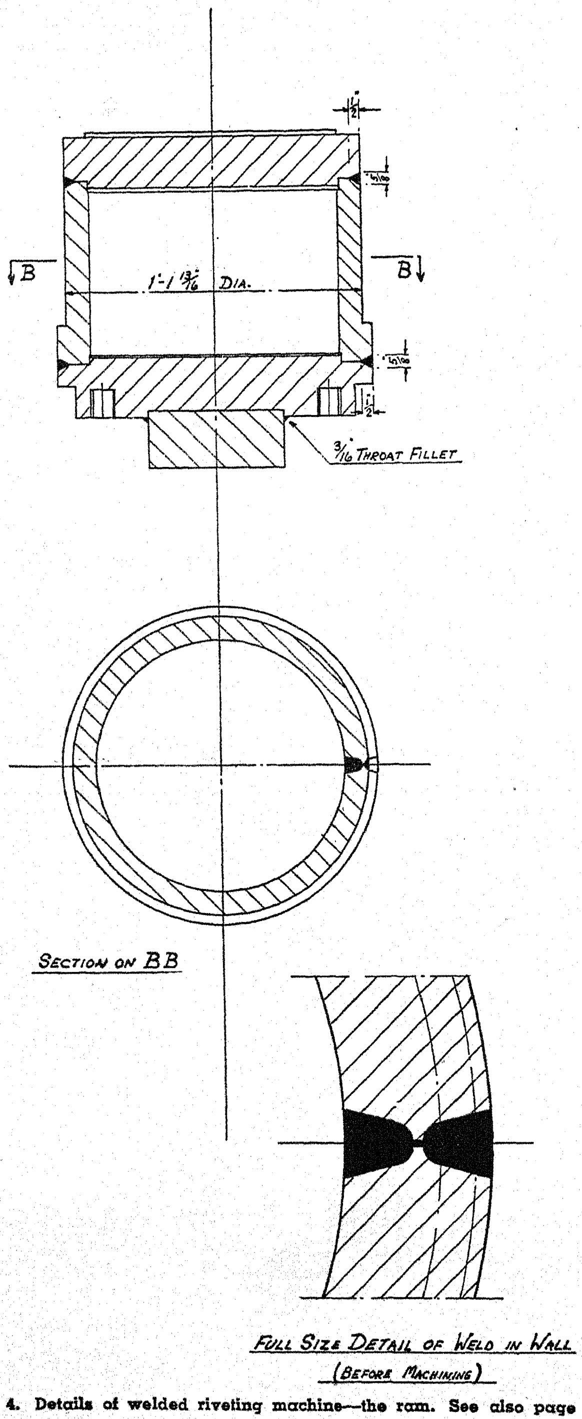


Fig. 4. Details of welded riveting machine—the ram. See also page 999b.

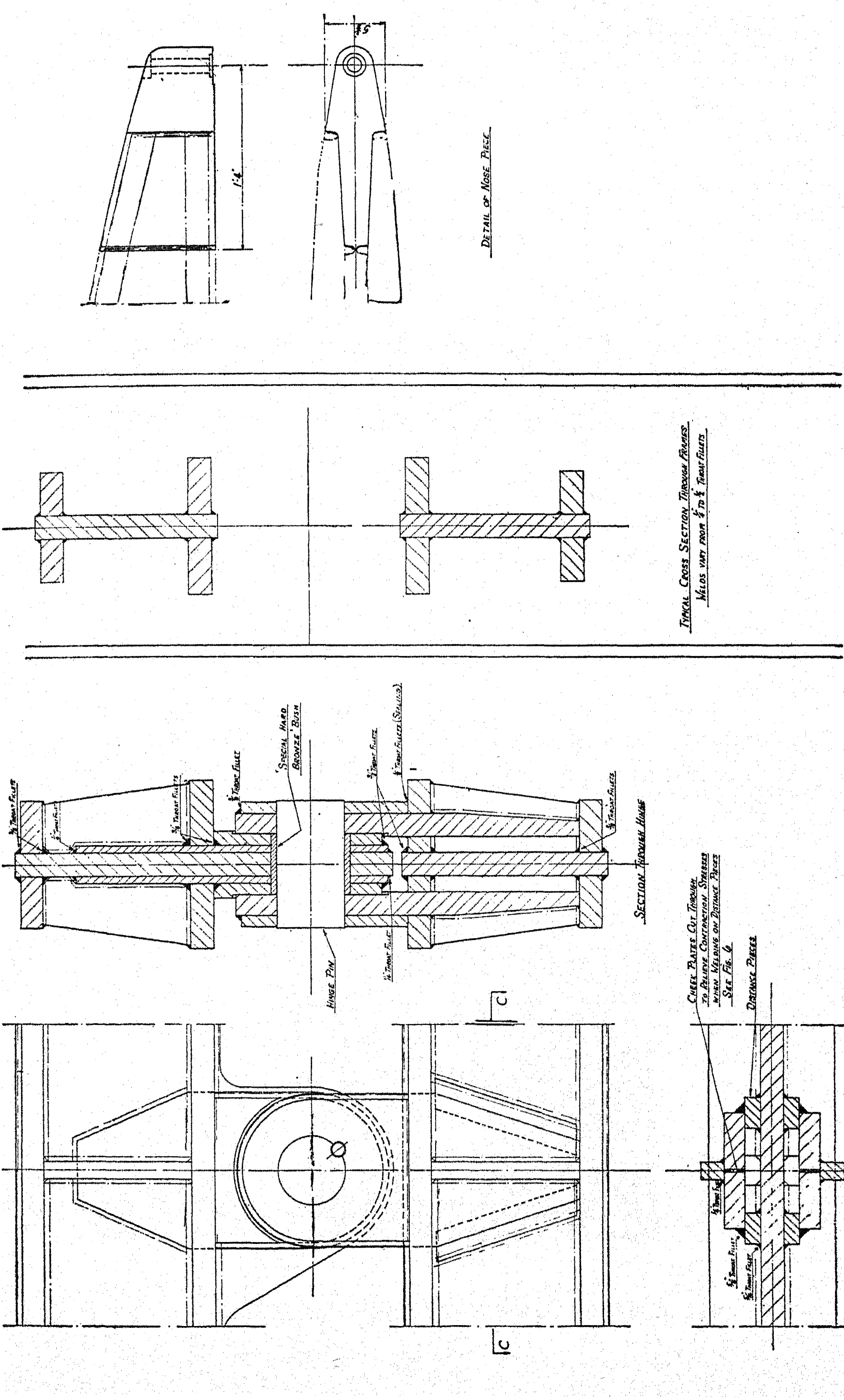


Fig. 5. Details of welded riveting machine: left, hinge; center, frames; right, nose piece.

The plate forming the wall of the ram is bent and welded as described for the cylinder. The circular top and bottom plates are then welded on and the ram assembly finish-machined as shown by Fig. 4, right.

The detail of the hinge is shown by Fig. 5, left. In the case of one frame the web plate is extended and reinforced by doubling plates to form the male eye bearing. In the case of the other frame, distance pieces are welded to the web and to these distance pieces cheek plates forming the female eye are welded. As the distance pieces, when welded on, form rigid supports, the cheek plates are cut through to relieve the contraction stresses on the welding of these plates.

It will be noted that in the cross section of the frame, Fig. 5, center, the flanges are split and the web carried through. This has the advantage over the conventional design where the web butts against the flanges in that the welding is spread over eight light runs instead of four heavy runs, that is, to resist the same horizontal shear, an economy of about 50% is effected in the welding. Further, with this method of construction the difficult butting of the flange on to the curved shape of the web is avoided.

The special type of welded-in nose piece has been applied for the first time to this particular machine. The design is shown by Fig. 5, right. Where the depth of the frame requires to be a minimum the shaped forging is made thick to develop the shear. As the depth of the frame increases, the forging is correspondingly reduced in thickness until a point is reached where the plate web can safely carry the shear stress.

The component parts of each frame are assembled complete by tack welding. The final welding is then carried out after preheating, care being exercised to distribute the welding heat as evenly as possible to avoid distortion. In the case of the cylinder frame, the back end is machined after welding for the reception of the cylinder. The boring of the cylinder and all other machining is carried out after welding

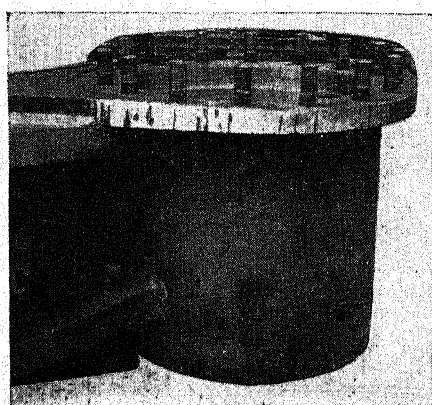


Fig. 6. Cylinder of jack unit welded to frame and machined.

The details are further illustrated by photographs, (Figs. 6, 7 and 8, taken from a machine of smaller gap (4′6″), which was ordered at the same time.

Fig. 6 shows the cylinder of jack unit welded on to frame and machined. It will be noted that the web plate is shaped at the bottom to form a register for the cylinder, and that the top plate of the cylinder is extended to give a good connection to the tension flange of the frame.

Fig. 7, (top), shows the detail of hinge on upper or plain frame.

Fig. 7, (bottom), shows the detail of hinge on lower, or cylinder frame.

Fig. 8, (top), shows the special nose piece welded to upper frame and bored.

Fig. 8, (bottom), shows the special nose piece welded to lower frame and left unbored until machine is completely assembled.

Advantages of Welded Design.—In comparing the two types of machine, the welded design has the following important advantages:

(1) The saving in cost of the welded design over the cast steel design is £134. 0. 0d., ($1651.24), that is, £319.16. 0d., ($1554.23), less £185.16. 0d., ($902.99) = 42%.

Deducting from both costs the parts which are common to both machines, that is, £37. 1. 0d., ($180.06), the saving is even greater, amounting in the present case to 47½%.

(2) While the welded machine described above refers to a particular machine for a particular application, the welded machines generally show a saving in cost as compared with the cast steel machines where patterns are existing. This saving showed a marked increase as from last year, due to the high rates for steel castings. Where new patterns have to be made, the saving is increased by the cost of the patterns. There is also a further saving in respect of the machining costs on castings which turn out defective. Apart from these monetary savings the welded machines have proved themselves to be more reliable than the cast machines. Having regard to these factors, the gross saving accruing to industry is, therefore, very considerable.

(3) The welded machine can be designed more efficiently than the cast steel machine. In the latter type the material has to be increased at certain points in an endeavour to have the thicknesses as uniform as possible, and having regard to the unreliability of the steel castings, we have found that it is inadvisable to exceed a tensile stress of 14,500 lbs., per square inch. In the welded machine the material need be no thicker than required to develop the stress, and as the material can be relied on to be sound, we are able to work to a tensile stress of 22,500 lbs. per square inch for the specified material.

(4) There is complete freedom from sudden fracture in the welded machine. The writer knows of two cases where the long arm of a machine, with cast steel frame, snapped across and fell a considerable distance to the ground. This grave defect is entirely eliminated by the welded construction, and even if the design were weak, the welded

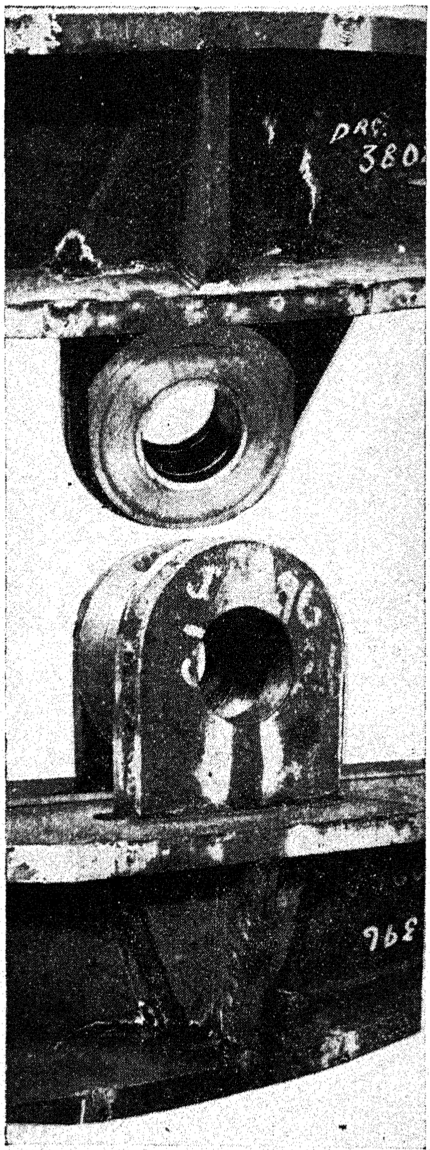


Fig. 7, top, detail of hinge on upper frame; bottom, hinge on lower frame.

frame would not crack across as in the case of a casting, but would show the weakness by becoming bent.

(5) It has been proved that the welded design is lighter than the cast steel design. Although the saving in weight in the present case is only 11½%, this is due to the restricted space available for the machine. For a standard machine of similar dimensions, the saving in weight would be about 20%. This advantage results in a corresponding saving in cranes and handling appliances, and a saving in manual effort on the part of the operator in swinging the machine. The writer recalls a case about ten years ago, where an economical riveting proposition had to give way to an uneconomical one owing to the fact that cast steel machines could not be designed within the lifting capacity of the existing cranes. This proposition would today present no difficulty. On the lines of the design described above, the writer has confirmed that the weight of the welded machine would have been well within the capacity of the cranes.

(6) The welded design brings more wages into an industry such

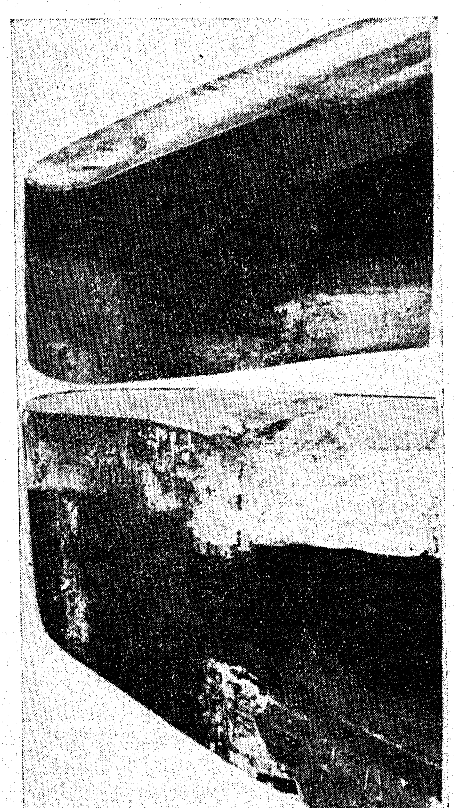


Fig. 8, top, nose piece welded to upper frame and bored; bottom, nose piece welded to lower frame.

as ours, where we have to purchase steel castings from an outside firm. On comparing the relative labour costs, it will be seen that in this particular case the increase is 100%.

From the above, the writer submits that the welded design increases the service life, efficiency, general economy and social advantage to mankind, and at the same time the designers and manufacturers of such welded machines feel that they are making a definite contribution to engineering science by helping in this important branch of industry.

Chapter V—High Speed Metal Forming Press

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The power press manufacturing field is of such a highly diversified nature that the arc welding method of fabrication lends itself readily to its product. Prior to the advent of arc welding as a commercial means of fabrication of massive parts, castings were used exclusively for the irregular parts of these machines. Since the orders for this type of equipment are very seldom for more than one or two of any one kind, the pattern cost which must be included in the selling price of each machine is quite a factor. Then, too, the storage of such patterns as are required is an item to be considered because replacement may be necessary in the future.

The application of welded design immediately cancels the pattern and pattern storage cost that is required when cast construction is used. Further, in the cast method of construction the metal most commonly used for the parts is cast iron which, due to its weaker properties, requires more massive sections than steel for the same strength. Of course there are places where the strength requirement is such that cast members, including the pattern cost, are more economical than arc welded parts, but these places are in the minority.

The time element also plays a very important part in the construction of most presses. When prompt delivery of a machine is required, welded design offers another distinct advantage over the cast method of construction. In most cases the time that would be required to produce the necessary patterns for a cast product is more than ample to cover the welding time on the job. Thus, the foundry time is gained in favor of quicker delivery.

The appearance of the finished product is becoming more and more important as time goes on, and here again the arc welded structure, if designed for appearance as well as strength, can be made more pleasing to the eye than the replaced cast product. The cost of the painted finishes on welded presses is much less than on cast machines. This is due to the fact that most castings require a layer of filler material to smooth the rough spots before the paint can be applied. With welded construction the plates are already smooth and only require painting to produce a satisfactory finish. The box-type sections employed for the members also add to the appearance of the press by presenting smooth surfaces to the eye rather than external ribs and flanges predominant in cast design.

To best point out the savings which the arc welded method of fabrication has made possible, a detailed description of the development of a small high-speed press is set forth.

The machine under consideration is a power press of the type used for metal forming and stamping. As auxiliary equipment to the

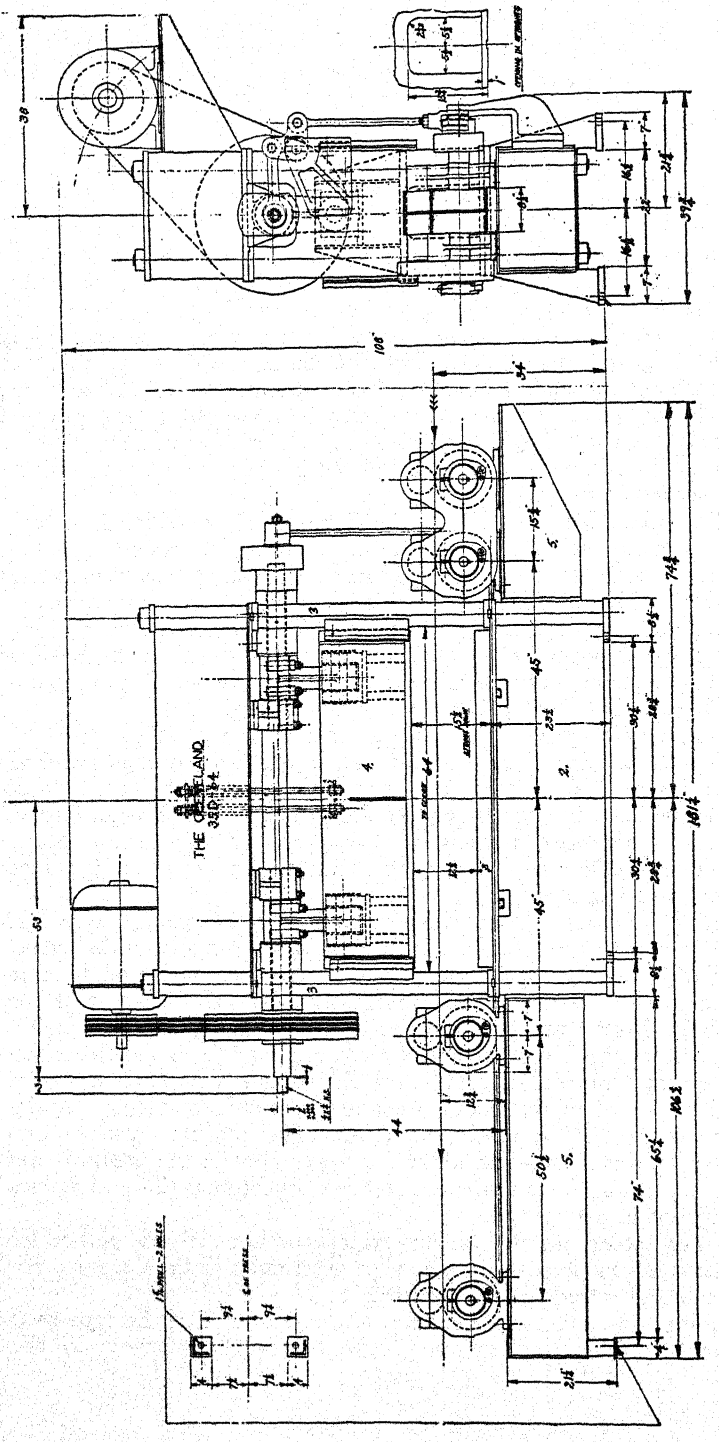

Fig. 1. Assembly of press complete except for dies.

machine proper there is a roll feed consisting of forming rolls and tension rolls for pulling the strip stock from under the dies after each stroke of the press. The drawing, Fig. 1, shows the complete machine except for the dies.

The essential parts of the machine as indicated in Fig. 1 are: 1—the crown; 2—the bed; 3—the uprights; 4—the slide; 5—the roll feed supports; and the crankshaft, flywheel, connections, and roll feed parts.

In the construction of a machine of this type the bed, uprights, and crown are assembled and then held in place by four tie-rods. These tie-rods, at the four corners of the machine, are shrunk in to a predetermined stress to hold the parts as an assembled unit and also to transmit the forces from the bed to the crown.

It is possible to construct a press frame of one piece and thus eliminate the tie-rods, but in the design under consideration this was impractical. There are several objections to a one-piece frame for a press of the type being described. Since the tie-rods are pre-loaded to a much higher value than the rated capacity of the press the uprights will not elongate under load as would be the case if tie-rods were eliminated in favor of a one-piece construction. The machining of a one-piece frame would also lead to difficulties as well as would the handling and set up for machining.

Design Description.—In the previous design of a like machine, castings were used instead of welded members, but in the change from

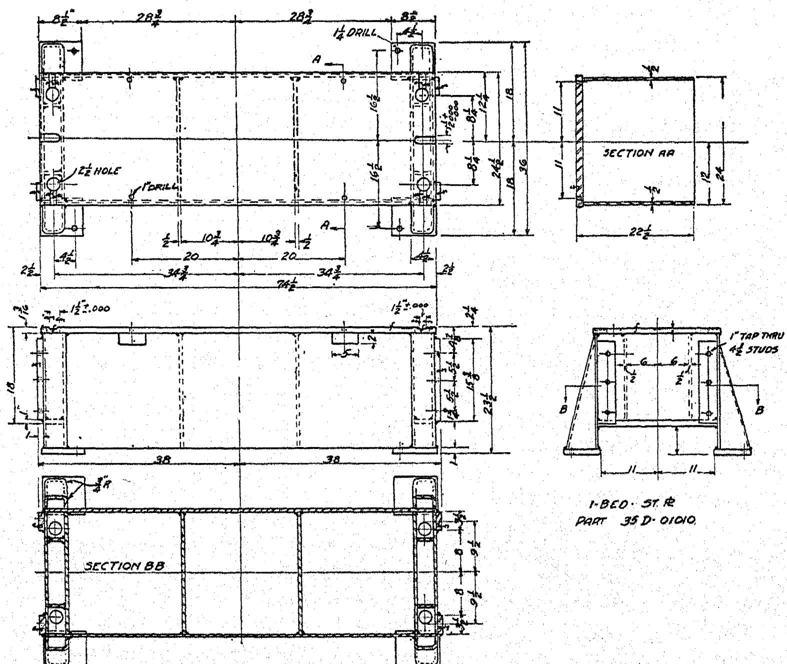

Fig. 2. Details of press bed.

cast to welded design more factors than the mere replacement of members, welded for cast, was considered. Several changes in the method of construction were made to more fully benefit from the advantages welding offered. Every possible member of the machine was not made of welded construction, but instead, as many members as afforded good design were made by the welding method and the few small parts where strength—especially in tension and bending—was not necessary were made of cast iron. This last statement explains the method of attack used in the design of the machine under consideration. The method of design of the parts will be presented in an effort to show that the procedure led to the most economical design of the machine

The Press Bed.—Fig. 2 is a detailed drawing of the bed showing the plate sizes and location of the welds. There are certain specified dimensions required by the customer which limit some phases of the design of any product. In the present machine, the dimensions on Fig. 1 were the governing ones. The depth of the bed front to back, although not shown in the figure, was specified to be 24½″. With the bed area dimensions and the height of the top of the bed from the floor given, the problem reduces to the design of a member of sufficient strength incorporating these sizes.

One more requirement that is demanded by most press users is that the deflection of the bed shall not be greater than 0.001″ per foot of span when loaded to its maximum tonnage. From this fact, and knowing the rated capacity of the machine, 32 tons, the size and shape of the main stress members was computed.

A benefit that steel offers over cast iron as a construction material is that it is equally strong in both tension and compression. However in the present bed design this advantage was not used to the fullest degree because the top plate of the bed required strength enough to support and transmit loads from the center of the bed to the vertical plates. To offset the disadvantage of the heavy top plate, thin vertical members were used, and while a symmetrical section was not achieved, the depth of the section was made great enough to give the required stiffness and strength. The tension stress is the maximum safe value this type of equipment permits, and although the compression stress is a little low, the metal in the section is utilized to almost its fullest advantage because the calculated deflection is also maximum. To give strength to the member in the front-to-back direction, the vertical tie plates joining the two main span plates were included in the design.

The method of placing the plates and joining them is of interest because the design either stands or falls on its ability to withstand the loads subjected to it. As can be seen from the figure the top plate and front and rear vertical plates run the full width of the machine and the rest of the plates are tied into these members. To join these plates, fillet welds made from both sides were used wherever required, and at the points where welds from only one side were possible the plates were scarfed to assure proper penetration.

The leg construction was simplified by forming the plates to a U contour and welding these pieces in place. This decreased the welding a little and also added to the appearance of the bed.

The Slide.—The slide or ram of the press is a very good place to point out gains which can be accomplished in welded design over cast methods of construction. This part is a moving member and as a result its weight is very important, especially so in this particular machine because of the high speed at which it is operating, 400 strokes per minute.

The slide design was approached with the idea of obtaining as light a slide as possible and still have the proper strength requirements. At first thought, it appeared that the conventional slide be modified in design only as far as metal thickness was concerned and constructed of steel plate. This did not prove satisfactory because the lower pitman bearings would require heavy metal sections, and the welds would be rather large using the I type section as was employed in previous cast designs. To eliminate these two problems a box type slide was developed as is shown in Fig. 3. Instead of trying to incorporate the lower pitman bearings in the slide by welding, loose pillow blocks were used. The pillow block mountings, as shown in the figure, also simplify the machine work on the slide.

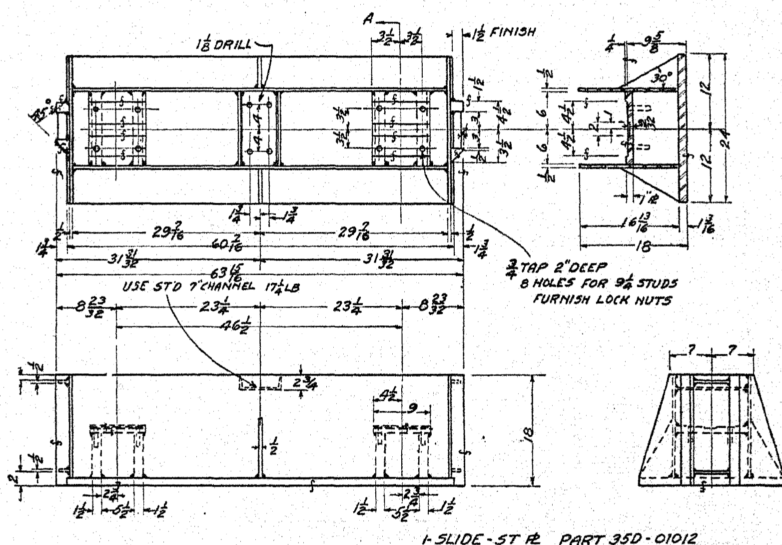

Fig. 3. Details of box-type slide.

The pillow block mountings not only serve as pads but also tie the two vertical walls together. At the center of the slide, there are two more tie members welded in, the lower ribs transmitting part of the load from the flange into the vertical plates, and the upper channel stiffening the plates. The channel section is also used to support the rods for holding the spring counterbalance required on the machine.

The end plates of the slide tie together the plate ends completing the box-type construction developed for this slide. The vertical strips on which the ram is guided were then welded to the end plates to finish

the member. As can be seen on the drawing, the plates were set in far enough from the edges of the joining plates to permit fillet welds at most places. The resulting design produced a slide that was sufficiently strong to take the loads required of it and yet was light enough to not cause any undue load on the bearings.

The Crown.—The crown of this machine, redesigned for the use of welded construction, shows another departure from the conventional press crown. In the usual cast crown, the bearings are an integral part of the casting, but in the present design it was found, as with the slide, that loose pillow blocks could be used to better advantage.

When considering the use of pillow blocks, over incorporating the bearings in the fabricated pieces, several points must be considered. In welding in bearings, either steel castings or bearing blocks cut from steel plates are used, and these would be of a size requiring rather heavy welds. Since the members above these blocks are of rather thin section this would not be to the best advantage in the design. Fig. 4 is a detail of the crown, and it can be seen that all the plate thicknesses, except for the pads to mount the bearing blocks and the tie-rod nuts, are ½″ making comparatively light welds possible. Of course, integral bearings would work out to better advantage on presses of larger capacities because all the plates making up the parts would be heavier.

The conventional press of cast construction makes use of an I section to carry the loads transmitted to the bearings. This type section has the required rigidity in a vertical plane but may lack the required rigidity in the horizontal plane due to the small moment of inertia in this direction. This is especially true when the load on the press is taken high up on the stroke because the higher up on the stroke the load is taken, the greater the horizontal force component on the crown.

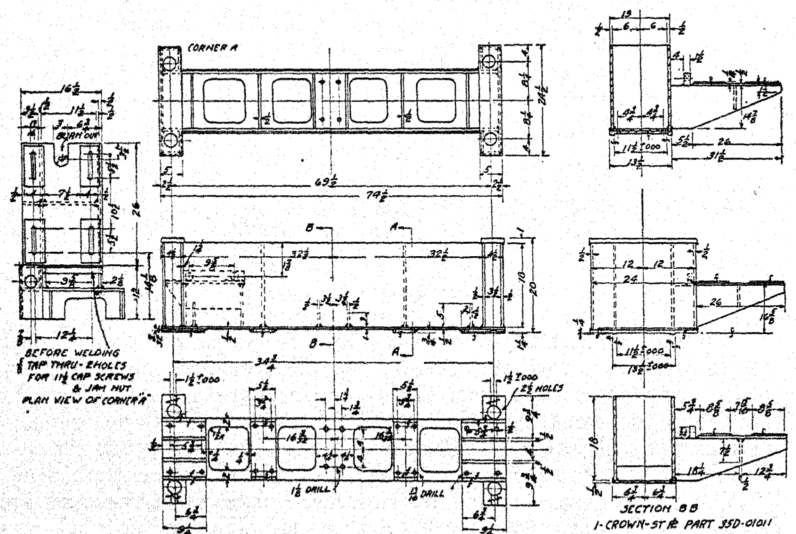

Fig. 4. Details of crown.

To obtain a crown rigid in both the horizontal and vertical planes, a box-type structure was used. This gain in strength in the horizontal plane was at no extra expense to the completed product because the location of the plates determined the strength in the horizontal plane once the section required for the vertical loading was determined.

The method of placing the plates and other details of construction can be seen in the figure. The two long members, the main strength members of the crown, run the extreme length of the crown and are welded to the outside and plates which make up the tie-rod inclosures. The bottom plate, also running the whole span, is welded to the vertical plates to make up the rigid box section, section B-B in the figure. To stiffen the member, at more places than just the end, the two vertical plates over the center bearings were added. Also, over the end bearings short stiffening ribs are located.

In all, the resulting crown is of light construction and yet more rigid than an equivalent cast piece.

Uprights.—The uprights for the machine are purely compression members so that insofar as the material used, cast iron or steel, there is very little difference. This made it necessary to consider the relative

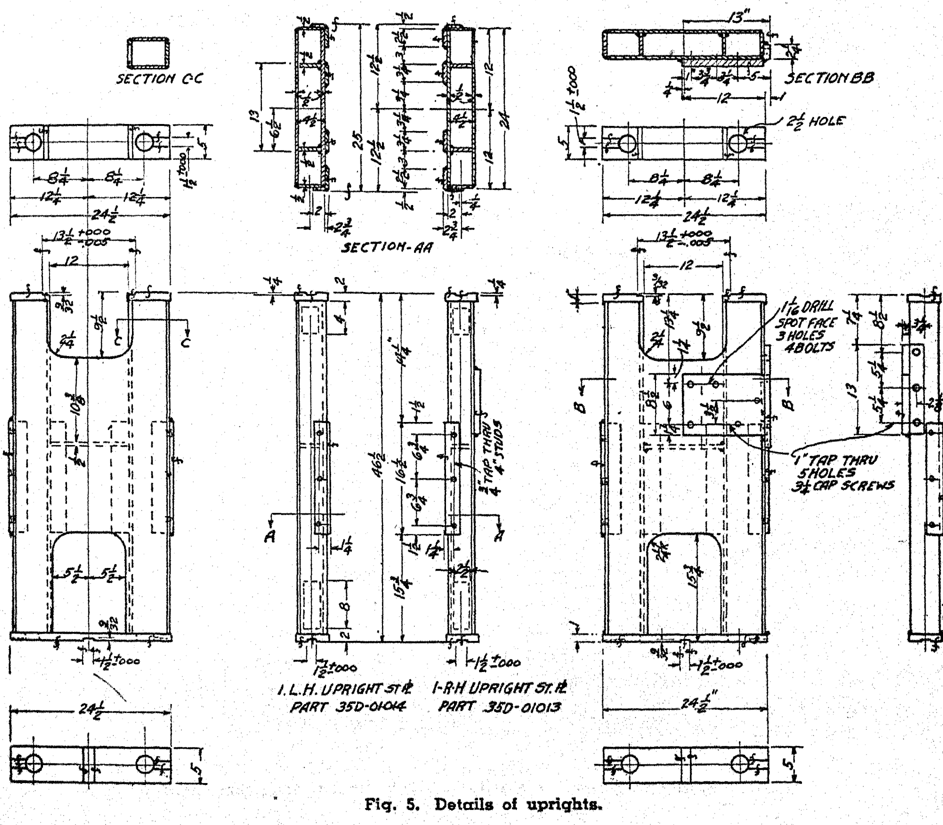

Fig. 5. Details of uprights.

possibilities of the two construction materials still further to determine which would produce the most economical design. Since the machine is of a special type and only one is being produced, the cost of the pattern for the cast uprights would have to be absorbed in the cost of the machine. This would prove very wasteful because a pattern of such a part usually can be used to produce some 20 or 30 castings before replacement is necessary and yet in this case the selling price of one machine would have to be adjusted to take this added expense. With this in mind a welded steel upright was decided on.

Fig. 5 is a detailed drawing of the completed members. The uprights are so short in comparison to their width that they can be considered as direct compression members. Section A-A on the drawing shows the placing of the vertical plates forming the column sections. As will be noticed, two of the narrow plates are only welded to the outside plates on one side of the upright. This condition does not exist for the entire length of the column but only for a distance of about 12 inches where the welder could not reach inside to place the welds. This is not a disadvantage to the design because the weakest section in the member is at the bottom of the upright where the hole is cut through for feeding stock to the machine, and this section is sufficiently strong for the machine.

At the bottom and top of the uprights, 1″ plates were welded to finish off the ends and act as footings when the members are as-

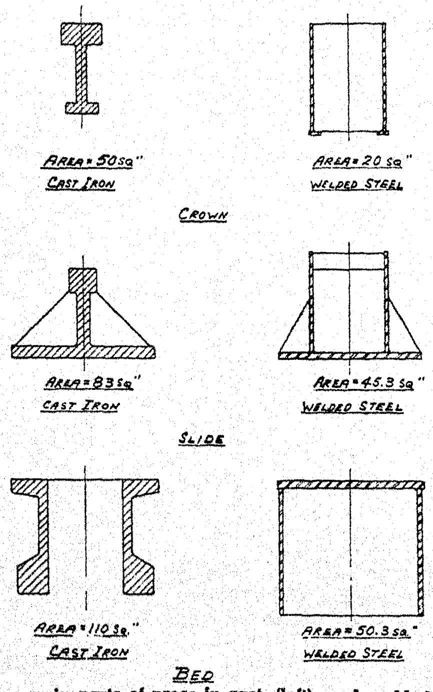

Fig. 6. Three main parts of press in cast, (left), and welded construction.

sembled. The pads welded to the uprights are for mounting the gibs and also for mounting a gear box.

Brackets.—The brackets mounted at the ends of the bed, Fig. 1, are also of welded construction and here again the balancing of the costs of welded or cast construction was much in favor of the welded design. The weight consideration was also important because the righthand bracket is completely unsupported except where it is fastened to the bed, and the left hand bracket is quite long. When the machine is completely tooled up, another unit of considerable weight will be fastened to the left hand bracket between the two sets of rolls thus accounting for the large span between the rolls.

Welded Steel-Cast Iron Section Comparison.—To briefly present a picture of just how the distribution of metal in several of the parts of welded design differs from that in the conventional cast members equivalent cast sections were computed. These sections are the ones required at the critical points in the members, that is, the sections at the centerline of the machine. The welded members for the three main parts of the press together with the cast sections they replaced are shown in Fig. 6.

The governing values used in determining the sizes of the members were the deflections and tension stresses in the members. The sections are of such a nature that the compression stresses are always within the allowable when the deflection and tension stresses are maximum. It was possible to design the steel parts so that when the deflection was maximum the tension stress was also the maximum permitted, about 6000 lbs. per sq. inch.

The equivalent cast iron parts however could not be designed for such an economical distribution of metal. It was impossible to develop practical sections for the cast parts shown in the figure in which both the tension stress and the deflection reach their maximum values at the same time. The deflection values governed the design because all the stresses are below the allowable for cast iron, 3000 lbs. per sq. inch, when the deflection is maximum.

TABLE I—GOVERNING LOAD VALUES

	Deflection			Stress-Ten.		Area	
	Max.	C. I.	Steel	C. I.	Steel	C. I.	Steel
Bed	.0058″	.0056″	.0058″	1520	6100	110″	50.3″
Slide	.0038″	.0038″	.0032″	2585	6250	83″	45.3″
Crown	.0058″	.0059″	.0060″	1740	6000	50″	20″

From the stress values, it can be seen that the cast iron sections could not be used to their fullest advantage in the present design. It may be argued that more advantageous cast sections could be designed, but it must be borne in mind that metal thicknesses and specified die areas must be worked into the construction to produce the lightest weight members for the loads they must withstand. The steel parts, however, are more economically designed due to their greater depth and thinner sections which are impractical if not impossible in such castings.

TABLE II—COST OF WELDED PARTS

	Weight	Cost	Cost per lb.
Bed	1970	$290.00	14.7¢
Slide	1402	153.00	10.9¢
Crown	1175	137.00	11.65¢
Uprights (Two)	990	177.50	17.95¢
Right Hand Bracket	431	60.50	14.04¢
Left Hand Bracket	867	90.00	10.4¢
	6835 lbs.	$908.00	13.12¢ Aver. Cost per lb.

The cost of the welded parts may seem a little high at first glance, but when it is considered that this cost includes labor, materials, and overhead up to the machining operations the price is reasonable. The costs listed were the actual cost of each piece, and the cost per pound was calculated to show the variation in fabrication cost of the different parts.

The weight of equivalent cast members to replace the welded parts was calculated by the use of the areas listed in Table I and the weights of actual castings that were made in the past for machines of almost the same specifications. The weight of cast parts was computed to be:

Weight of Cast Parts

Bed	3730 lbs.
Slide	2020 lbs.
Crown	1590 lbs.
Uprights (2)	1260 lbs.
R. H. Bracket	950 lbs.
L. H. Bracket	1650 lbs.
	11200 lbs. Total weight

The cost of the castings, basing the value of the iron at 4½¢ a pound, would be $504 which is less than the cost of the welded parts, but no pattern costs are considered. Without detailed drawings of the parts designed for cast construction it is almost impossible to determine the exact cost of the patterns, but from past experience and a knowledge of the overall dimensions of the different parts an estimate of the pattern cost was made. The cost of the patterns required for the seven pieces was estimated to be about $1600. When this pattern cost is added to the cost of the castings the cost of a set of castings for one machine amounts to $2104 which is more than double the cost of the welded parts.

Assuming that only one machine of this kind is wanted, which was the case in the present design, the net saving on the parts up to machining amounts to $1196. This saving does not constitute the entire saving the welded design gave however. There were savings in the machining time because less metal was allowed for finishing. The lighter parts made assembling easier, and the final finish, the painting, was less expensive.

Another cost that does not appear on the books until later is the pattern storage expense in the case of a cast product. This may not be a large item when only a few patterns are needed but an accumulation of patterns from a number of different machines soon adds con-

siderable to the fixed overhead of a company, and this in turn is reflected in the cost of the product.

In the machine under consideration the difference in cost of the welded steel and cast iron parts may tend to throw weight in favor of the cast construction in the event that enough identical machines were being constructed at one time to offset the pattern and other costs. It would require the construction of at least 4 identical machines to make the choice of construction immaterial insofar as costs are concerned, but in the production of 4 machines by the welding method the fabrication technique would improve and the result would be lower welding costs.

Assume that the average cost per pound of the welded parts could be cut to the lowest individual price per pound value listed in Table II, 10.4¢ per pound. This would make the cost of the welded parts for each machine about $711, a decrease of $197. This new cost of welded parts is still above the casting cost when no account is taken of pattern costs, but when all the factors are considered the welded method of fabrication shows a saving over the cast method of construction in quantity production as well as when only one set of parts is required.

Summary.—The development of the design of the main members of a power press has been presented in considerable detail to show that parts must be designed for the welded method of construction and not just copied from previous cast designs. This design for welding approach has produced a machine of equal or greater strength than the cast machine and, at the same time, the appearance of the product was improved.

The saving in cost attained by the welded construction amounts to approximately 57% when only the pattern cost is included in the cost of a comparable cast machine. Even when the quantity of machines produced is increased, thus dividing the pattern costs, the welded method of construction is more economical.

The adoption of welding for the fabrication of the major parts of a machine decreases the necessity of maintaining large foundries, pattern shops, and pattern storage departments, and in many cases these units can be eliminated. In place of these departments a weldery would have to be set up, but this would not constitute a large investment.

The raw material, steel plate, that would have to be carried in stock in the welding department would not add greatly to the department overhead, and it is a simple step from the steel plates to the desired parts as compared to the hindrances which the casting method offers. In all, the welded method of fabrication not only lends itself nicely to the power press field from the design angle, but also from the economical angle as well.

Chapter VI—Arc Welded Fabrication of Spiral Casing for Water Turbine

By Herbert Stone,
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This paper concerns the fabrication, by electric arc welding, of a mild steel spiral casing forming part of a water turbine, (See Fig. 1), which was manufactured by Messrs. Markham and Co., Ltd., of Chesterfield, England, to the order and designs of Messrs. Boving and Co., Ltd., hydraulic engineers of London, and the information contained herein, excepting in so far as it is general, has been obtained by the author

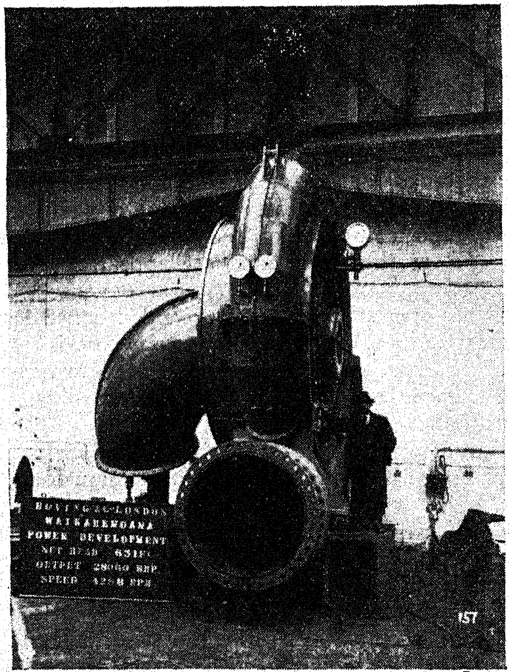

Fig. 1. Horizontal Francis type turbine with arc welded spiral casing. Photo courtesy Boving & Co., Ltd.

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The turbine is of the horizontal Francis type and was supplied to the public works department of the New Zealand government for the hydro-electric plant at Waikaremoana, South Island. The machine is coupled to an alternating current generator of 22,200 KVA, and de-

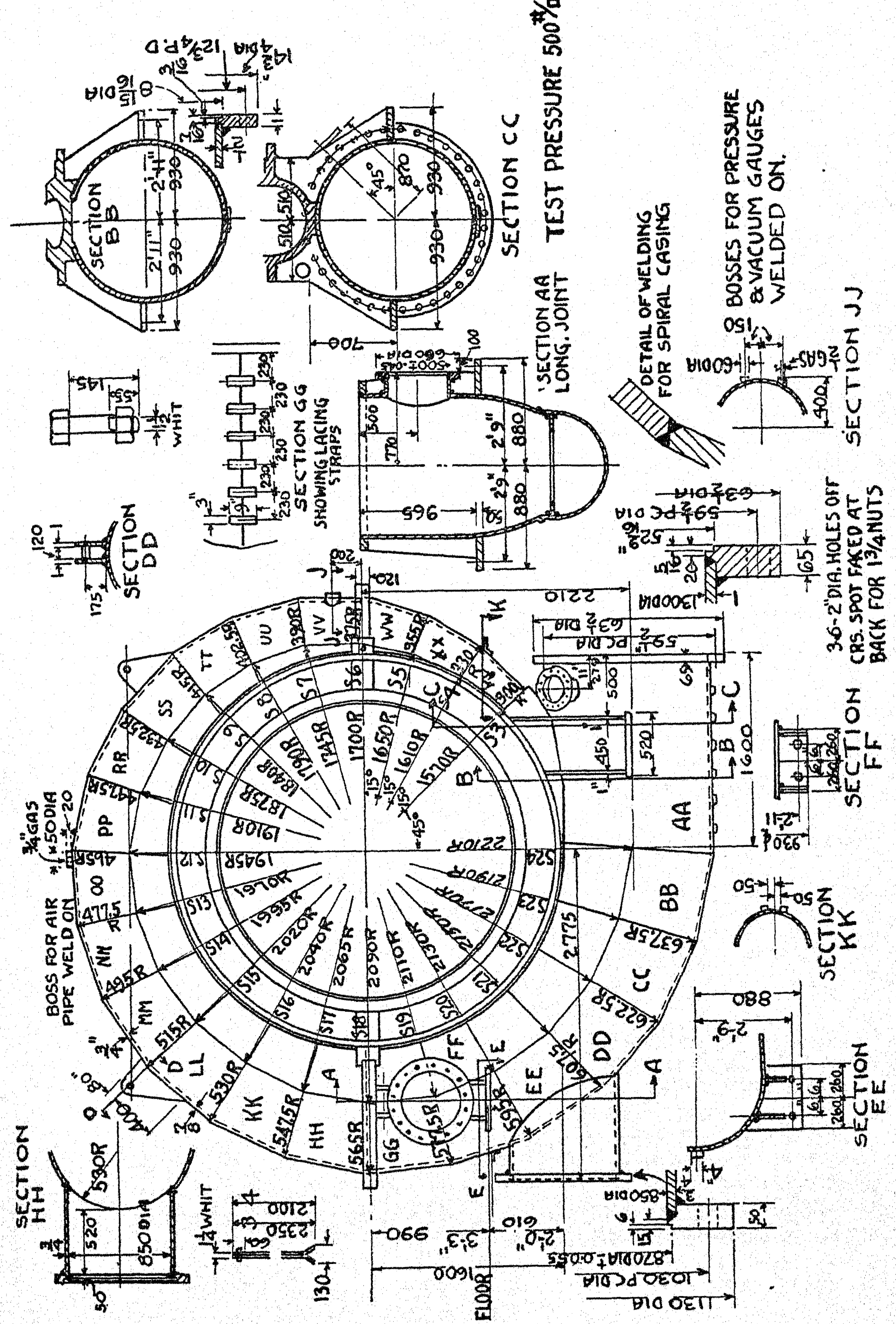

Fig. 2. Design of arc welded spiral casing.

velops a maximum of 28,000 H.P. at a speed of 428.6 R.P.M. under a head of 631 feet.

Why Welding Was Adopted.—A brief history of the job from the beginning will show why the casing was made by welding.

The manufacturers are general engineers with about 900 employees. The works comprise iron and brass foundries, pattern, machine fitting and erecting shops, forge, and constructional steelwork shops.

In common with the majority of English concerns of similar size, there is no steel foundry, and steel castings are purchased outside. This was an important factor influencing the decision which was later reached.

The original enquiry called for the spiral casing to be constructed wholly from steel castings, stress being placed on the importance of quick delivery, and a price was quoted embodying the most favourable steel founder's estimate.

The order to proceed with the work on the basis quoted was received after considerable lapse of time, and steps were taken to place the order for the necessary steel castings.

A serious difficulty, however, immediately arose. A tremendous expansion of business had taken place since the quotation was made, and no British steel founder was willing to undertake the casting within the original time.

The best offer received was to commence work in three months and deliver six months later.

As this time would not have allowed the required delivery date to be kept, an alternative had to be considered.

The manufacturers, therefore, proposed that they should fabricate the casing from mild steel plates by electric arc welding. Although they had not completely welded such a casing, they possessed such experience of large welded work generally as to enable them to submit the suggestion with complete confidence.

The designers obtained the permission of their customers to make this change and redesigned the job as a fabrication.

Design for Welding.—The final design is shown in Fig. 2.

The casing is of composite construction incorporating a massive cast steel stay ring, split across the horizontal center line into two halves, to which the plates comprising the body are welded to form upper and lower halves.

The inside diameter of the water inlet passage is 1300 m/m or 4′—4″, and at the plates, which vary in thickness from 1″ at the inlet to ⅞″ and finally ¾″ at the smaller diameters, are butt welded at the circumferential seams and lap welded to the cast steel ring.

The flange at the inlet has an outside diameter of 5 ft. 3½″, and a finished thickness of 65 m/m, or 2⁹⁄₁₆″ while those at the joints are 60 m/m or 2⅜″ thick.

Three branches for the relief valve, manhole and by-pass, are welded to the lower half of the casing, to which in addition are welded four feet for supporting the turbine on the foundations.

The overall dimensions of the casing are 17 ft. 10″ by 16 ft. 5″.

The question may be asked why the design was not carried to its logical conclusion, and probably simplified by dispensing with castings altogether.

If the turbine had been designed for a lower head, the casing would have been completely fabricated, but because of the high head in this case the stay ring is the most highly stressed portion of the casing requiring heavy section material, which if fabricated, would have presented difficulties in smithing, and it was therefore decided that a steel casting for this part was the better alternative.

The design calls for the casing to withstand a test pressure of 500 lbs. per square inch, and this necessitates a joint efficiency at the welds of 100 per cent.

To obtain this, the butt joints are bevelled on both sides as shown in detail on Fig. 2.

Welding.—In considering the procedure to be adopted in the welding of the casing, it was decided to use coated electrodes of well known make Grade 5, since several years experience gained by the company in the use of these electrodes, proved that consistent results are readily obtainable.

In choosing the sizes of electrodes to be used, it was decided not to allow the use of electrodes smaller in diameter than $3/16''$, but at the same time to avoid the general use of the largest sizes, $5/16''$ and $3/8''$.

The reason for this decision is the investigation on this subject published in the Journal of the American Welding Society for December 1934, and commented on by Boyd and Cape in their paper presented at the Symposium on the Welding of Iron and Steel organized by the British Iron & Steel Institute in 1935.

Manufacture.—On receipt, the stay ring castings were rough machined on the flanges, leaving on $1/8''$ for finishing, the flanges drilled, the two halves bolted together and rough machined in the bore, leaving in 12 m/m or approximately $1/2''$ for finishing after welding, this being done for the purpose of relieving residual stresses in the castings.

In the meantime, and previous to the receipt of the castings, as much preliminary work as possible had been put in hand. The plates of the casing had been developed, cut to shape, rolled to correct radii, and the plate edges bevelled for welding.

The mild steel flanges also had been forged, rolled, welded at the joints, and rough machined to within 2 m/m of finished sizes in order to effect economies in the final machining operations after welding. The smaller flanges were completely pre-machined and drilled before welding, as also were the four feet.

The operation of fitting the plates to the castings was then taken in hand, the two castings, bolted together, being set level on a flat table upon which the positions of joints, flanges, and branches, had previously been marked.

Each plate was smithed on the two extreme edges to fit the radius of the casting at the lap joints, a certain amount of this being done by means of local heating with oxy-acetylene flame, but the greater

proportion by smithing from a fire, shaping the plates to templates previously prepared from the casting.

All portions of the casting in contact with weld metal were chipped bright with pneumatic chisels.

As each plate was fitted it was tack welded to the casting and to the neighbouring plate, care being observed to ensure even butting of the plates and a regular internal contour.

In order to avoid vertical and overhead welding, it was decided to split the stay ring castings at the joint as soon as the plating was sufficiently far advanced, thus making it possible for the welding of the lower half of the casing to proceed at the same time as the plating of the upper half.

When all plates on the upper half had been tacked into position, the final welding of this section was taken in hand and completed while the last plates comprising the small diameter of the lower half were fitted into position.

Work was now concentrated on the completion of the lower half, which comprised the greater proportion of the work, and the inlet flange, the three branches, and the four feet, were tacked into position as accurately as possible, and the job then set up on an accurate marking-off table and there checked.

Set lines were marked on the casing in all positions necessary, in order that the branches and flanges could be adjusted as required before final welding, and on completion of this checking, the lower half casing was finally welded.

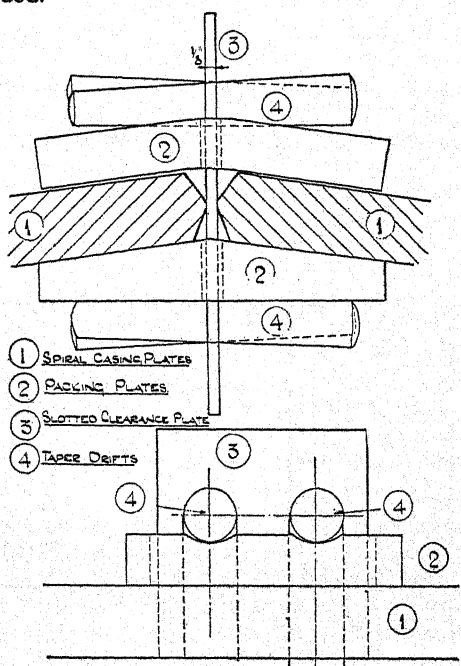

Fig. 3. Application of butt closer for welding spiral casing.

The general procedure adopted for the butt welds consisted in depositing one run of $\frac{3}{16}''$ diameter in the bottom of the vee and following this with one or two runs of $\frac{3}{16}''$ or $\frac{1}{4}''$ as required by the plate thickness.

A gap of $\frac{3}{16}''$ at the bottom of the vee in the $\frac{7}{8}''$ and $1''$ thick plate and $\frac{1}{8}''$ in the $\frac{3}{4}''$ plate for the butt joints was maintained by the use of butt closers of the type illustrated in Fig. 3.

The plates were pulled up to the casting before tack welding by the use of bolts and clips welded on as required.

Welds were examined as the work proceeded, and in cases where complete penetration to the bottom of the vee appeard to be doubtful, the underside of the groove was opened up by chipping with a narrow round-nosed chisel to ensure that the first run of welding on the reverse side was deposited on the weld metal previously put down.

In order to keep a check on any tendency towards distortion, trammels were made and set lines marked on the casing plates from fixed points on the casting before final welding commenced, frequent checks being made of these dimensions, as the work proceeded.

It was considered desirable, in order to avoid setting up undue stresses in the welds, to complete the circumferential butt welds before the longitudinal welds connecting the plates to the casting.

By this means, the plates were free to expand or contract lengthways, the light tacks between the plates and the casting shearing when excessive stresses were set up.

In welding the butt joints, two welders were engaged on each seam, one inside, and the other outside the casing. The inside man commenced at the end adjacent to the casting and worked round the bottom and up to the horizontal center line, whilst the man on the outside started from the center line and worked round the top to the ends of the plates at the casting. Thus, the two welders worked as nearly as possible diametrically opposite to each other.

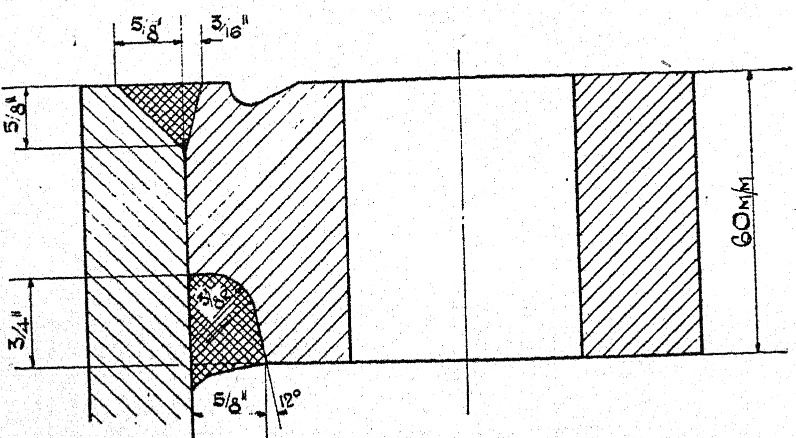

Fig. 4. Details of welds adopted for the large flanges.

When all the butt welds on one half of the casing had been part welded in this manner, they were completed by turning the job over and following the same procedure on the other side.

In the same way, the longitudinal lap welds connecting the plates to the casting were welded inside and out at both ends simultaneously.

Distortion was principally feared in the welding on of the large flanges.

The sketch Fig. 4. gives details of the type of weld adopted for these parts of maximum strength.

The danger of welds of this type is the tendency for the heavy welding at the back of the flange to cause dishing.

This trouble was eliminated by lifting the casing with the face of the flange downwards, and filling up the groove in six places spaced equidistantly round the circumference with heavy tacks about 6″ to 8″ in length.

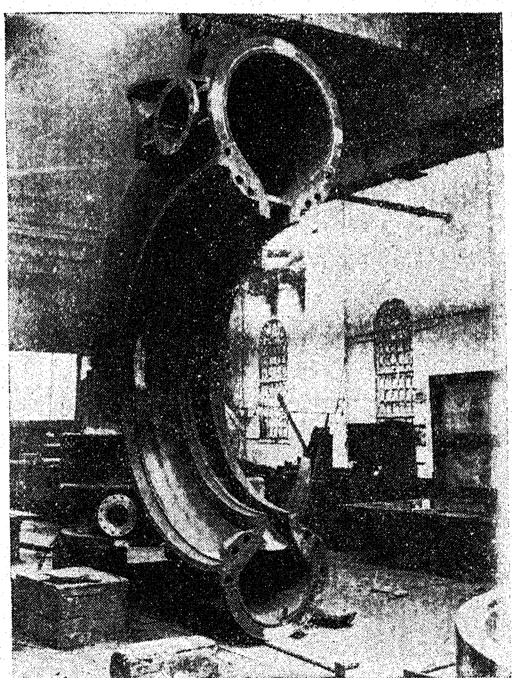

Fig. 5. Lower half of casing in position during welding of large inlet flange.

The photograph, Fig. 5, shows the lower half of the casing in the position described during the welding of the large inlet flange. This done, the casing was then lowered into a suitable position and the welding of the inside groove completed.

The job was then lifted again into the first position and the welding of the groove at the back of the flange completed with heavy electrodes $\frac{5}{16}$″ and $\frac{3}{8}$″ diameter.

Although this method involved a certain amount of extra lifting, this was proved to be justified, no distortion being observed, although experiments with alternative methods of welding similar flanges had produced distortion of as much as ¼″.

Inspection and Quality Control.—Four welders, chosen for their known qualities of reliable and consistent workmanship, were employed.

No special tests were imposed on these men, since this practice is not favoured by the author's company, as it has been observed to give unreliable results.

Supervision of the welding procedure was undertaken by the author as part of his normal duties.

As part of the usual works routine, and in order to keep a check on the work performed by each of the men employed on the job, each welder was required to stamp his work where begun and ended with an identification letter.

The systematic and regular inspection of work whilst in progress, by a person competent to advise and instruct the welders engaged, is believed to be the surest method of maintaining a high standard of quality in welded work.

In order to estimate the capabilities of different welders, it is necessary for shop executives to make themselves thoroughly familiar with each man's work by means of regular observation, careful note being made of the following points:

(1) Current value selected.
(2) Soundness of weld metal.
(3) Fusion of weld with parent metal, a watch being kept for signs of under-cutting.
(4) Whether care is being taken carefully to clean off slag before commencing a fresh run.

The type of electrode to be used, and the precautions to be observed in order to minimize the risk of distortion should be indicated to the welder before commencing each job.

When dealing with experienced men, however, it is unnecessary to specify amperages too closely, since work of the same standard is frequently produced by different welders using different current values, and any attempt to impose close limits on current values to be used with various sizes of electrodes usually results in a general deterioration in the quality of the work produced.

It is the author's experience, however, that there is a general tendency for welders to select too low an amperage.

This fault may be detected by observation and should be corrected at sight, attention being drawn to the greater ease of working and improved appearance of the finished weld to be obtained by a higher current.

Tests of the welds apart from the final hydraulic test were not specified by the customers, but as a matter of works routine two tensile tests were taken.

The first test piece was taken from a portion cut from the longitudinal welding of the 1″ plate at the inlet. The second was cut from the longitudinal joint in the ¾″ plate comprising the relief valve branch.

Both test pieces being cut circumferentially from plates rolled in circular form, were cold-flattened in order to provide suitable test pieces.

The following are the results obtained:

Test No.	Original size ins.	Dimensions Area Sq. ins.	Distance between gauge points	Elong. inches
1.	1.000 1.010	1.010	2″	.36
2.	.989 .750	.742	8″	1.33

Yield stress on section Tons	Yield stress on section Tons/sq.″	Ratio of Yield to Max. Stress	Max. Stress on section Tons	Max. Stress on section Tons/sq.″	Elong. %	Reduction of area %
23.44	23.21	80.9	28.98	28.69	18.0	22.5
18.60	25.07	77.3	24.07	32.44	16.60	56.9

Test piece No. 1. broke in the grips.
Test piece No. 2. broke clear of the weld.

In order to avoid any possibility of trouble from welding defects at the final test, as much of the welding as convenient was pre-tested hydraulically.

This method was applied particularly to the lap welds connecting the plates to the steel casting, and the welds at the flanges.

A small clearance existed between the casting and the plates and also round the inside of the flanges, and holes were, therefore, drilled through the plates and into these clearances, care being taken that the drill was not allowed to penetrate into the steel casting or the flange. In all, 24 of these test holes were drilled and tapped ½″ gas thread.

A portable hydraulic pump was then connected to each hole in turn, pressure being raised to a maximum of 800 lbs./sq. inch and maintained for several minutes.

Any defects discernible were chipped out and rewelded, the repairs being later re-tested in the same manner.

The value of the above precautions was proved at a later stage when the completed turbine was erected and the casing subjected to the specified hydraulic test pressure of 500 lbs./sq. inch.

At this pressure the whole of the welding was carefully examined and was found to be perfectly sound, an occurrence which brought congratulations from the inspecting engineers engaged.

Time Chronicle.—The photograph, Fig. 6, shows the status of the job three weeks after the castings had been received in the welding shop.

Up to this time, the usual 8½-hour day had been worked, and at this stage the castings were split.

In order to expedite completion, double shift welding was now instituted with two welders on each shift working a total of 41 man hours per day.

By this means, the welding of the lower section from the inlet to the joint was completed in five days.

Welders were then transferred to the upper section, which was

completed in a further five days, during which period the final plating and checking of the lower section had been completed.

Four days welding then sufficed to complete the work, and the preliminary testing then occupied approximately a further week.

Almost a week was also lost, as the Christmas and New Year holidays fell at this time.

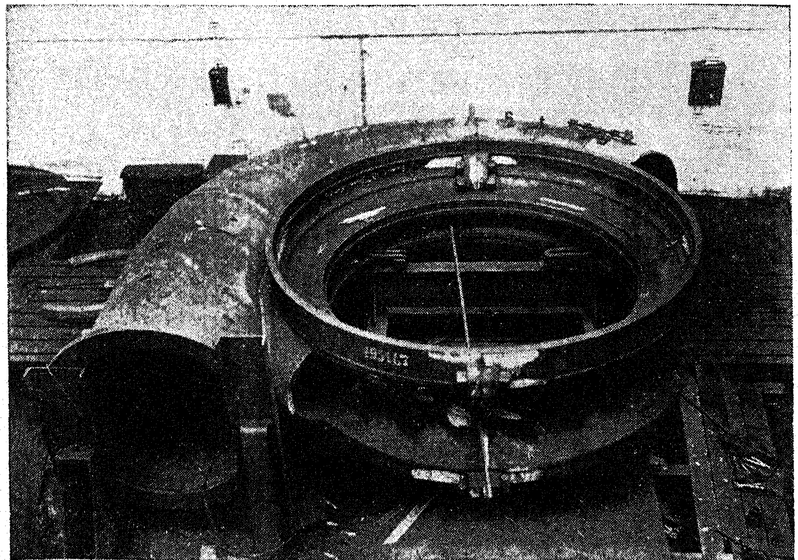

Fig. 6. Arc welded casing with stay ring.

The time taken to complete the whole of the fabrication and preliminary testing was seven and a half weeks.

It is expected that the experience gained will result in further economies in time when similar work is undertaken in the future.

Advantages of Welded Construction.—The principal standard by which an alternative method of engineering production can be judged must be that of final cost, and in making cost comparisons the following questions require consideration: (1), Service life; (2), efficiency; (3), handling charges; (4), manufacturing time; and, (5), final appearance.

From the explanation previously given, it will be noted that the cost was not the principal reason which influenced the change in design.

It would have simplified the author's task to have taken as his example less complicated welded jobs which would show to greater advantage than the present case, but it is submitted that the results described below are very satisfactory when the job is considered as a whole and the amount of additional complication taken into account.

The following are the advantages which may be recorded in the present case:

(1) The fabricated casing is equally as strong as the original design and, thus, the service life of the casing is not affected.

(2) The smooth interior finish of the plates and flush welds is much superior to that of a steel casting. This should lead to an improvement in hydraulic efficiency.
(3) A reduction of weight automatically reduces the handling charges.
(4) It is estimated that manufacturing time was reduced by a period of from two to three months.
(5) It will be noted from the photograph, Fig. 6, that the smooth surface of the welded plates enhances the appearance considerably, which in power station equipment is an important consideration.

When compared with the estimated weight of the cast steel alternative, the saving in weight which was realized is shown as follows:

Estimated finished weight. Cast steel..........21 tons
Actual finished weight. Fabricated..........15.75 tons
Saving in weight: 5.25 tons, or 25 per cent.

Analysis of Welding Costs.—

Total footage of welding..........600 ft.
Welding time, man hours..........800
Welders' earnings..........£51. 0. 0., ($247.86)
Average cost labour per hour..........15. 3d.
Power cost per KWH.......... .55d.
Electrodes consumed..........1380 lbs.

Lbs. of electrodes per foot of weld: $= \dfrac{1380}{600} = 2.3.$

Welding speed feet per hour: $= \dfrac{800}{600} = .75$ ft.

Labour cost per foot:

$$= \frac{\text{Labour per hour}}{\text{Welding speed ft./hr.}} = \frac{15.3}{.75} = 24\ 06\text{d.}$$

Power cost per foot:

$$= \frac{(\text{Amps.})\qquad(\text{Volts})\qquad(\text{Cost per Unit})}{(\text{Efficiency of set})\qquad(\text{Welding speed ft./hr.})\ (1000)}$$

$$= \frac{220 \times 35 \times .55}{.6 \times 75 \times 1000} = \frac{4235}{450} = 9.41\text{d.}$$

The above assumed 3/16″ electrodes used throughout and an average efficiency of 60% for the single operator motor-generator welding sets which were used. Electrode cost per foot:

= (lbs. of electrodes per foot of weld) (Cost per pound)
= 2.3 x 5.5 = 12.65d.

Total cost per foot: Labour..........24.06
Power.......... 9.41
Electrodes..........12.65

46.12d. or 3/10.12d.

As the above figure is dependent on two assumptions, an analysis of the cost accounts provides a more accurate figure, the cost of welding, including all charges, arrived at thus being 3/7.15d. per foot.

An advantage of welded construction of particular value to general engineering firms, is that of keeping work in the firm's own plant.

Savings resulting from this may be summarized as follows: 1, More work available for the manufacturer's own employees; 2, Overheads are spread over a greater number of jobs, resulting in an all-around reduction per job; 3, Manufacturer's own staff having complete control over all stages of the work assures close supervision and, in cases of urgency, the necessary impetus can be applied by the people most directly concerned; 4, Considerable savings may be effected by pre-machining as much as possible before welding, and by reducing machining allowances generally; 5, The risk of failure during test, after all work has been completed, which is always present with steel castings, can be entirely eliminated.

Advantages which are ultimately of benefit to mankind in general are represented in the present case as follows: (1), increased efficiency; (2), general economy; and (3), reduction of manufacturing time.

Of the first, although supporting figures are not yet available, there is reason to believe that the hydraulic efficiency should be slightly improved.

Of more importance, however, is the economy in material which electric welding has made it possible to achieve without any reduction in efficiency or strength, which is exemplified by a 25 per cent reduction in weight.

This is an economy which is of utmost importance to mankind in general, since it assists the conservation of raw materials.

Regarding the third advantage, the saving in manufacturing time which has been noted, enables manufacturers to increase turnover, and is of benefit to customers in enabling machinery to be completed and put to work at an earlier date.

Conclusion.—Business demands that designers and production engineers shall endeavour continually to exploit to the full all methods of production which will tend to reduce manufacturing costs, and it is for this reason that such rapid advances in the application of electric arc welding have been made in recent years.

At the same time, few engineering processes have suffered more from conservatism and prejudice, and it is to be regretted that these twin evils have not yet been entirely eradicated.

In this connection it is of interest to record that arising out of the successful completion of the job which has been described, two similar turbine casings are now being designed.

In compiling this paper, the author sincerely hopes that the description of the methods adopted, the savings in time, money, and materials, proved to have been realized, and lastly, the proved efficiency of the completed work, will encourage other engineers to apply electric arc welding to the solution of their particular difficulties, and thus share in the advantages which have been outlined.

The author desires to thank Messrs. Markham & Co., Ltd., and Messrs. Boving & Co., Ltd., for permission to publish the matter contained in this paper, and also Messrs. F. Williams and E. Mensforth, directors of the former company, for helpful criticism and advice.

Chapter VII—Prewelding of Turbine Blades for Propeller Units of High Capacity

By L. M. Davis and J. M. Mousson,
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Introduction.—Similar to the experience in many other fields of machinery, construction materials used for hydraulic turbine manufacture have not kept pace in every way with advancements in design. The higher specific speeds brought about by the advent of the propeller type turbine and the steady increase in heads under which these turbines are being employed, makes these conducive to a destructive phenomenon, which, though not new, has grown in intensity to such an extent as to affect not only the successful operation of many units already installed, but at the same time may, without proper measures, seriously impede further progress in the art of hydraulic turbine construction. There is little doubt that no other subject has more vitally interested hydraulic engineers in recent years than this hydraulic phenomenon called "cavitation" and its destructive effect upon the turbine blades called "pitting."

Various solutions have been suggested in the past and even at the present time different views are entertained. In Europe, where propeller turbines of the Kaplan type were first introduced and therefore more widely employed, it was soon discovered that under conditions conducive to cavitation, cast carbon steel blades could not withstand the punishment. A belief that pitting was in some measure related to corrosion fatigue led to adoption of solid cast stainless steel turbine blades.

The first blades of this kind were manufactured by progressive Swedish turbine builders. Although the tempered solid stainless 14% chromium steel blades were exceedingly costly, their adoption was thought justified and advocated in the light of the already large initial investment required for hydroelectric plants in general. At the same time, it was argued that turbines with stainless steel blades would no longer be subject to aging, thereby preserving not only their original performance characteristics but rendering unnecessary future replacement costs. Of importance was also the possible omission of shut-down periods required for turbine repairs preventing periodic losses in energy generation which could be appreciable for units of high capacity installed at plants where the river discharge is equal to or in excess of the maximum station draft throughout the year. Notwithstanding the high cost of solid stainless steel turbine blades, turbine manufacturers of Continental Europe also adopted them at least for higher heads (in excess of 30 feet) with apparently satisfactory results.

In the United States, where experience to be acquired from gradual development of turbines of this kind was lacking, and where no reliable and comparative operating records could be made available, engineers

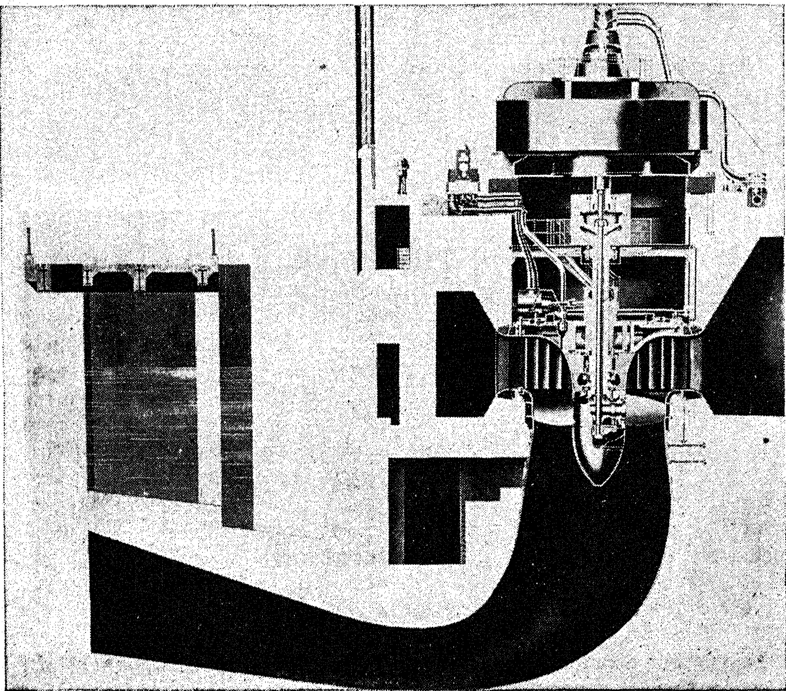

Fig. 1. Cross section through one 42,500 horsepower Kaplan unit at Safe Harbor.

were not prepared to decide on stainless steel turbine blades. When the first four large Kaplan turbines were built in this country to be installed at the Safe Harbor hydroelectric development on the Susquehanna River during 1931 and early 1932, it could not be overlooked that in spite of the many arguments in favor of stainless steel, there were neither sufficient foundry experience nor adequate facilities on this side of the Atlantic at that time to produce successfully the 20 solid stainless steel turbine blades weighing about 12,000 lbs. each in finished condition (See Fig. 1). No American manufacturer would assume the risk, and, despite European experience, there were still considerable doubts and uncertainties regarding the proper alloy content and heat treatment for the cast stainless material in order to obtain the resistance required. At the same time it was realized that if serious pitting of the carbon steel blades were to occur, ample opportunity for experiments would be available due to the rather unusual runoff characteristics of the Susquehanna River providing for periods of low flow sufficient in length to develop proper repair procedures without any sacrifice in the utilization factor of the plant.

In view of the above, it may be seen that practical consideration led to an entirely different approach in this country. Rather than adopt without question methods and procedures developed abroad, it was thought possible instead to continue the use of low priced carbon steel

for the large turbine blade castings and if required find sufficient surface protection of some kind through experimentation.

Field Experience.—Operating experience with the first four Kaplan units at Safe Harbor showed that carbon steel blades could not withstand the punishment by cavitation. Sizable areas on the suction side of the blades were found to be pitted after eighteen months of service. Pitted areas were also noted on the peripheral surfaces of the blades where narrow clearances make repairs particularly difficult due to limitations in accessibility (See Fig. 2).

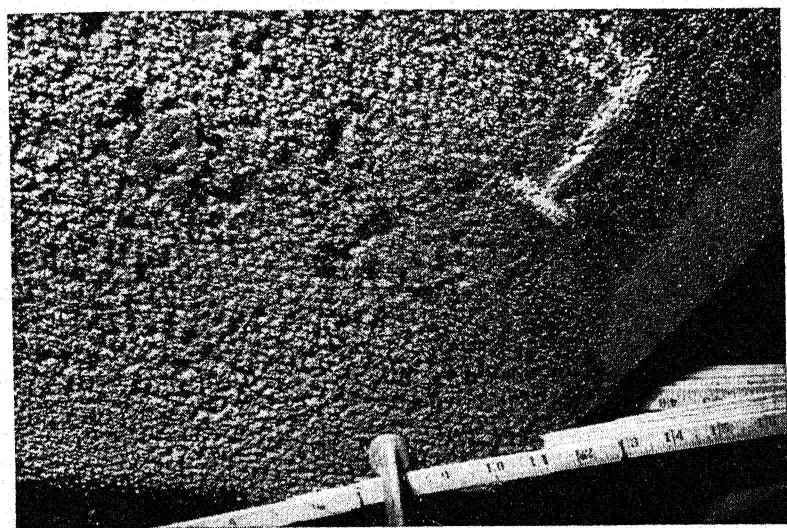

Fig. 2. Part of pitted area on suction face of unprotected cast steel turbine blade at Safe Harbor.

Although pitting had by no means progressed to a point where the blades were seriously damaged, a general over-hauling was carried out at the first convenient opportunity. The affected areas were chipped to the solid parent metal, resurfaced with two coats of stainless 18-8 chromium nickel steel electrodes and ground to a smooth finish. The particular material was chosen because, with the units in place, all welding had to be done overhead and this type of welding electrodes was found particularly suitable for this kind of work.

At the same time, pioneering efforts on repairing cast iron Francis turbine runners at the nearby Holtwood plant of the Pennsylvania Water & Power Company had shown excellent resistance of stainless 18-8 welding deposits. While the results obtained at Holtwood were satisfactory, it was thought that cavitation conditions at Safe Harbor may be more severe and that it was not at all certain that this material would prove adequate.

Subsequent inspection after the initial repairs showed that the areas surfaced with this particular material stood up satisfactorily. The smooth ground surface of the deposits revealed effects of cold working

similar in appearance to the product of peaning. The unevenness on the surface could hardly be felt by hand and was best discernible by lighting effects. However, marked pitting was again discovered on a wide band of parent metal immediately adjacent to the welded areas. In view of this, it could be surmised that periodic repairs would continue for several years or until the welded areas had reached the boundary zone of cavitation, a sizable percentage of the entire suction face of the turbine blades, assuming the welding deposits continued to hold up.

In 1933, an identical fifth unit was installed but in the light of the field experience the peripheral surfaces of the blades, difficult to weld in the field, were prewelded in the shop with stainless 18-8 chromium nickel electrodes.

Laboratory Research.—In 1934 the installation of a new unit was contemplated, but for this turbine special operating requirements had to be met. While all units previously installed were built for the generation of 3-phase, 60-cycle current, this new unit was to be the first and only one for some time at Safe Harbor to generate 25-cycle, single-phase current for railroad supply. In view of this, only infrequent and short outages could be arranged for, making it imperative that suitable precautionary measures be taken in building the new turbine to render the punishment from cavitation ineffective or at least reduce pitting to a minimum. Since no marked progress in the casting of stainless steel had been made up to this time and carbon steel turbine blade castings had already been manufactured in advance, it was felt that prewelding these blade castings would likely furnish the proper solution to the problem, provided the decision regarding the welding material could be made on a reliable basis. In spite of the satisfactory results obtained in course of the maintenance work with stainless 18-8 chromium nickel steel electrodes, it had to be recognized that our experience was limited to about one year.

In order to gain experience rapidly an extensive research was initiated to determine the metallurgical aspects of pitting as produced by cavitation. A special apparatus was built providing accelerated testing conditions. Acceleration was achieved to such a degree that a test run of only 16 hours would correspond to several years of service at Safe Harbor. Although this research was later extended to include cast, rolled, forged acetylene welded and sprayed materials, it will suffice here to discuss the results obtained with electric arc welding deposits. Regarding the proper selection of the welding material, it should be emphasized, however, that the pitting resistance by itself could not be used as the only criterion to the exclusion of any other consideration. As may be seen later on, manufacturing procedures had also to be given careful consideration to arrive at the proper solution, which, while a compromise, could best satisfy all requirements.

The test specimens of 1/4 x 1 1/4 x 4 in. were machined and ground to a fine finish. The amount of pitting was determined by weighing the specimens before and after the test. For comparative purposes, however, the loss in volume was used to compensate for the difference in specific gravity of the various materials (See Fig. 3).

Fig. 3. Typical cavitation test specimen. 1¼ times actual size.

Comparing the results on electric arc welding deposits as shown on Tables I, II and III, it may be noted that in general the plain and low-alloyed deposits showed the least resistance, the stainless chromium steels the highest, with the austenitic stainless chromium nickel alloys in between. Furthermore, it may be observed that the losses appear to follow a general trend, namely, the harder the deposit the smaller the loss. Some of the apparent inconsistencies may readily be explained by the difference in susceptibility to increase in hardness due to cold working. The Brinell hardness as given in the tables refers to measurements obtained on areas of the specimens not subjected to cavitation. Rockwell tests in the pitted zones showed an increase in hardness which was more pronounced for the materials having better cold-working characteristics such as the austenitic 18-8 and 24-12 varieties of chromium nickel steels. In view of the above, it may be surmised that if high original hardness could be combined with a high susceptibility to strain hardening or cold working characteristics, such material would be exceedingly resistant to pitting. This is clearly demonstrated by Specimen No. 241 on Table III. Here the chromium and nickel contents of the electrode analysis were sufficiently lowered from 18-8 to approach in the deposit the 17-7 chromium nickel ratio, keeping in mind that some sizable percentage of chromium and very little nickel are lost in course of the welding operation. A combination of 17 per cent chromium and 7 per cent nickel shows this excellent resistance because this alloy is somewhat unstable showing martensite interspersed through the austenitic matrix which would account for the very high original hardness. At the same time a 17-7 or 16-6 chromium nickel alloy is more susceptible to cold working than the 18-8 or 24-12 chromium nickel steels.

From the results, it is further evident that the base metal is of influence as well as the number of layers, (See specimens 190–194, inc.). From welding practice in general, it is known that carbon may be picked up from the base metal by the first layer. In the light of the metallographic analysis of many specimens, free carbon may substantially lower the pitting resistance because any impurities, (and carbon in this case must be regarded as such), may serve as the nuclei for fatigue cracks or may be conducive to further a rapid progress of the cracks in breaking through to their location. Two layers of welding materials were regarded as a minimum, in view of the fact that the carbon content of the new turbine blade castings was about .30–.45

TABLE I. ELECTRIC ARC WELDED LOW ALLOYED STEELS

No.	Alloy	Chemical Composition—Percentage of								
		C	Mn	P	S	Si	Ni	Cr	Mo	
180	.07% Carbon Steel	.07	.33	.017	.03	.01				a
181	.08% Carbon Steel	.08	.35	.035*	.035*	.06				e
182	.13% Carbon Steel	.13	.30	.015	.03	.07				a
183	Mn Steel	.11	.39	.017	.02			.02		a
184	Mo Steel	.12	.60	.035*	.035*	.08			.50	e
185	Ni Mo Steel	.08	.60	.035*	.035*	.08	2.30		.30	e
186	Cr Mo Steel	1.25	.50	.04*	.04*	.50*		5.00	1.50	e

a: Actual Analysis. e: Estimated Analysis. * Maximum.

No.	Alloy	Data on Coating of Electrodes and Characteristics of Deposit					Cavitation Loss in 16 Hrs. mm^3 at 20° C.
		Origin	Type of Deposit	Base Metal	No. of Layers	Brinell Hardness	
180	.07% Carbon Steel	A	Normal Dep. of all Constituents	Wr't Iron	2	156	73.6
181	.08% Carbon Steel	B	" " " " "	" "	2	147	66.9
182	.13% Carbon Steel	C	" " " " "	" "	2	145	76.3
183	Mn Steel	C	7-8% Mn in Dep. from Coating	" "	2	156	39.2
184	Mo Steel	B	Normal Dep. of all Constituents	" "	2	158	86.9
185	Ni Mo Steel	B	" " " " "	" "	2	180	68.0
186	Cr Mo Steel	D	" " " " "	" "	2	258	18.6

per cent and therefore an appreciable infiltration of carbon could be expected in the first layer. At the same time, the loss in chromium and other alloy constituents could be expected to be appreciably higher in the first layer than in the second.

Since the cavitation loss of the Safe Harbor turbine steel was found to be 62.4 mm^3 at 20°C, it could be surmised that a substantial increase in resistance was to be obtained by adopting either a stainless chromium or a stainless chromium nickel electrode for prewelding. Although there was definitely a higher average resistance indicated by the former type of electrodes, it was not at all certain whether a straight chromium rod would be desirable due to the elevated hardness of the deposit which perhaps would cause difficulty in machining and grinding. This particular consideration was of vital importance because these were the first new runner blades to be machined prior to grinding in this country. To arrive at a conclusion, special tests for machinability were, therefore, deemed essential.

Machinability Tests.—In order to eliminate as many variables as possible, the tests for machinability were made on a spare cast steel turbine blade having the same composition as the Safe Harbor blades. Double layer deposits of seven of the most promising varieties of electrodes were made, each deposit covering an area about 6″ x 4″. Careful notes were kept as to the comparative ease of welding the various elec-

TABLE II—ELECTRIC ARC WELDED STAINLESS CHROMIUM STEELS

No.	Alloy	Chemical Composition of Wire—Percentage of										Data on Coating of Electrodes and Characteristics of Deposit					Cavitation Loss in 16 Hrs. mm³ at 20° C.
		C	Mn	P	S	Si	Ni	Cr	Mo	Cu		Origin	Type of Deposit	Base Metal	No. of Layers	Brinell Hardness	
190	Stainless 12% Cr Ni Steel	.06	.75	.023	.022	.44	.59	12.48	.....	.....	a	C	Normal Deposit of all Constituents	Wrought Iron	1	287	27.6
191	Stainless 12% Cr Ni Steel	.06	.75	.023	.022	.44	.59	12.48	.....	.....	a	C	" " " " "	" "	2	310	8.4
192	Stainless 12% Cr Ni Steel	.06	.75	.023	.022	.44	.59	12.48	.....	.....	a	C	" " " " "	Boiler Plate	2	319	8.1
193	Stainless 12% Cr Ni Steel	.06	.75	.023	.022	.44	.59	12.48	.....	.....	a	C	" " " " "	Welded. 15% C Steel	1	277	55.0
194	Stainless 12% Cr Ni Steel	.06	.75	.023	.022	.44	.59	12.48	.....	.....	a	C	" " " " "	Welded Stainless 18-8	1	291	3.8
195	Stainless 13% Cr Ni Steel	.06	.38	.013	.014	.74	.44	13.32	.....	.....	a	E	" " " " "	Wrought Iron	2	346	9.6
196	Stainless 13% Cr Ni Steel	.07	.55	.033	.01	.61	.32	13.57	.....	.....	a	D	" " " " "	" "	2	278	6.3
197	St'less 13% Cr Ni Mo Cu Steel	.06	.87	.035*	.035*	.90	.70	13.38	.58	.66	a	C	" " " " "	" "	2	295	16.3
198	St'less 13% Cr Ni Mo Cu Steel	.06	.87	.035*	.035*	.90	.70	13.38	.58	.66	a	C	" " " " "	Stainless Cr Steel	1	326	7.3
199	Stainless 15% Cr Ni Steel	.06	.39	.015	.03	.25	.10	15.53	.....	.....	a	D	" " " " "	Wrought Iron	2	258	7.1
200	Stainless 15% Cr Ni Steel	.06	.36	.022	.02	.36	.09	15.73	.....	.....	a	C	" " " " "	" "	2	349	8.8
201	Stainless 15% Cr Ni Steel	.06	.36	.022	.02	.36	.09	15.73	.....	.....	a	C	1.25-1.50% Mn Deposit from Coating	" "	2	366	8.8
202	Stainless 16% Cr Ni Steel	.16	.15	.03*	.03*	.32	.78	16.45	.....	.....	a	C	Normal Deposit of all Constituents	" "	2	293	5.3
203	Stainless 16% Cr Ni Steel	.05	.33	.015	.01	.035	1.09	16.81	.....	.....	a	D	" " " " "	" "	2	366	8.9
204	Stainless 17% Cr Ni Steel	.06	.39	.04	.01	.35	1.43	17.71	.....	.....	a	D	" " " " "	" "	2	390	7.8
205	Stainless 18% Cr Ni Steel	.13	.48	.013	.013	.....	.21	18.21	.....	.....	a	D	" " " " "	" "	2	350	6.9
206	Stainless 18% Cr Ni Steel	.13	.48	.013	.013	.....	.21	18.21	.....	.....	a	D	Some Softener Removed from Coating	" "	2	315	14.6
207	Stainless 18% Cr Ni Steel	.13	.48	.013	.013	.....	.21	18.21	.....	.....	a	D	More Softener Removed from Coating	" "	2	309	6.8
208	Stainless 18% Cr Ni Steel	.13	.48	.013	.013	.....	.21	18.21	.....	.....	a	D	Most Softener Removed from Coating	" "	2	304	9.1
209	Stainless 19% Cr Steel	.09	.47	.03*	.03*	.43	.....	19.03	.....	.....	a	C	Normal Deposit of all Constituents	" "	2	238	56.5
210	Stainless 19% Cr Steel	.09	.47	.03*	.03*	.43	.....	19.03	.....	.....	a	C	1.25-1.50% Mn Deposit from Coating	" "	2	285	22.7
211	Stainless 19% Cr Steel	.07	.65	.010	.01	.45	.09	19.24	.....	.....	a	D	Normal Deposit of all Constituents	" "	2	222	17.7
212	Stainless 21% Cr Cu Steel	.28	.....	......	.021	.36	.....	21.54	.....	1.02	a	D	" " " " "	" "	2	374	.0
213	Stainless 28% Cr Steel	.10*	.50*	.03*	.03*	.50*	.....	28.00	.....	.....	e	A	" " " " "	" "	2	262	11.1
214	Stainless 28% Cr Ni Mo Steel	.09	.....	......	.01	.46	4.24	27.92	1.49	.....	a	D	" " " " "	" "	2	256	3.5

a: Actual Analysis. e: Estimated Analysis. *Maximum.

Table III—Electric Arc Welded Stainless Chromium Nickel Steels

No.	Alloy	Chemical Composition of Wire—Percentage of											Data on Coating of Electrodes and Characteristics of Deposit					Cavitation Loss in 16 Hrs. mm³ at 20°C.
		C	Mn	P	S	Si	Ni	Cr	Mo	Ti	Cb		Origin	Type of Deposit	Base Metal	No. of Layers	Brinell Hardness	
220	Stainless 17-9 Cr Ni Steel	.09	.53	.010	.016	.....	9.86	17.49	.....	.....	.....	a	D	Normal Deposit of all Constituents	Wrought Iron	2	178	38.7
221	Stainless 17-9 Cr Ni Steel	.09	.53	.010	.016	.....	9.86	17.49	.....	.....	.....	a	D	" " " " "	" "	2	207	26.8
222	Stainless 17-9 Cr Ni Steel	.12	.60*	.05	.03*	.75*	8.84	17.78	.....	.....	.....	a	C	" " " " "	" "	2	206	23.4
223	Stainless 18-8 Cr Ni Steel	.07	.50	.035*	.035*	.50	8.75	18.25	.....	.....	.....	e	D	" " " " "	" "	2	218	24.6
224	Stainless 18-8 Cr Ni Steel	.07	.50	.035*	.035*	.50	8.75	18.25	.....	.....	.....	e	D	" " " " "	Boiler Plate	2	230	8.2
225	Stainless 19-8 Cr Ni Steel	.05	.36	.021	.013	.39	8.30	19.45	.....	.....	.....	a	C	" " " " "	Wrought Iron	2	204	13.8
226	Stainless 19-8 Cr Ni Steel	.05	.59	.023	.02	.72	8.64	19.24	.....	.....	.....	a	C	" " " " "	" "	2	222	8.5
227	Stainless 20-9 Cr Ni Steel	.05	.58	.03*	.03*	.47	9.71	20.55	.....	.....	.....	a	C	" " " " "	" "	2	188	37.1
228	Stainless 20-9 Cr Ni Steel	.05	.58	.03*	.03*	.47	9.71	20.55	.....	.....	.....	a	C	" " " " "	Boiler Plate	2	192	9.8
229	Stainless 20-7 Cr Ni Steel	.06	.74	.022	.026	.50*	7.68	20.66	.....	.....	.....	a	B	" " " " "	Wrought Iron	2	192	31.9
230	Stainless 21-7 Cr Ni Steel	.08	.79	.008	.006	.50*	7.86	21.88	.....	.....	.....	a	F	" " " " "	" "	2	265	17.6
231	Stainless 29-9 Cr Ni Steel	.10	.....	.....	.....	.....	9.00	29.00	.....	.....	.....	e	D	" " " " "	" "	2	260	16.5
232	Stainless 20-9 Cr Ni Mn Steel	.05	.56	.03	.03	.47	9.71	20.55	.....	.....	.....	a	C	1.25-1.50% Mn Deposit from Coating	" "	2	191	25.8
233	Stainless 21-10 Cr Ni Mn Steel	.06	1.62	.017	.01	.80	10.71	21.45	.....	.....	.....	a	D	Normal Deposit of all Constituents	" "	2	195	28.9
234	Stainless 18-9 Cr Ni Si Steel	.06	.57	.017	.015	2.30	9.43	17.98	.....	.....	.....	a	C	" " " " "	" "	2	216	12.1
235	Stainles 18-25 Cr Ni Si Steel	.05	.52	.017	.01	2.88	25.31	18.39	.....	.....	.....	a	C	" " " " "	" "	2	162	24.6
236	Stainless 18-9 Cr Ni Mo Steel	.07*	.40*	.03*	.03*	.50*	9.00	18.50	3.00	.....	.....	e	B	" " " " "	" "	2	227	16.8
237	Stainless 17-10 Cr Ni Mo Steel	.06	1.38	.016	.006	.43	10.62	17.67	2.40	.....	.....	a	D	" " " " "	" "	2	215	25.4
238	Stainless 19-9 Cr Ni Ti Steel	.04	.56	.022	.017	.42	9.80	19.86	.....	.25	.....	a	C	" " " " "	" "	2	198	14.3
239	Stainless 17-11 Cr Ni Cb Steel	.05	.32	.004	.009	.41	11.32	17.25	.....	.....	.84	a	D	" " " " "	" "	2	233	13.7
240	Stainless 20-9 Cr Ni Cb Steel	.07	.68	.024	.017	.43	9.42	20.42	.....	.....	.65	a	D	" " " " "	" "	2	193	16.2
241	Stainless 17-7 Cr Ni Steel	.11	.69	.025*	.025	.37	7.55	17.44	.....	.....	.....	a	C	" " " " "	" "	2	373	1.3

a: Actual Analysis. e: Estimated Analysis. *Maximum.

trodes, the time required to weld each deposit, and the pounds of deposit per pound of welding rod.

The actual machining of the test deposits was done by means of the machine, which later was used for the Safe Harbor turbine blades. Maximum machining speed and power input to the machine were determined for each specimen. Due to the warped surface of the blades, it was necessary to use a round point cutter, which left ridges between the cuts. After machining the test deposits, the ridges were ground off and the entire surface polished.

Visual inspection showed that six of the seven specimens resulted in a very good surface, the seventh being pock-marked with gas holes. A study of the data taken during machining indicated that three of the six good specimens were machined with difficulty due to non-uniform hardness. Another was exceedingly hard so that considerable difficulty with cutters may be expected with that material. Of the two specimens which passed the machinability test, one deposit was somewhat easier to apply than the other resulting in the adoption of an 18-8 chromium nickel welding electrode. (See Spec. No. 224, Table III).

Shop Welding of Blades.—From experience on the five units already operating at Safe Harbor, it was possible to predict approximately what portions of the blades would be subject to attack by cavitation and, therefore, should be prewelded. The areas which were prewelded are shown on Fig. 4.

Since considerable metal had to be removed in certain areas, the blades were rough machined and then the areas to be welded were

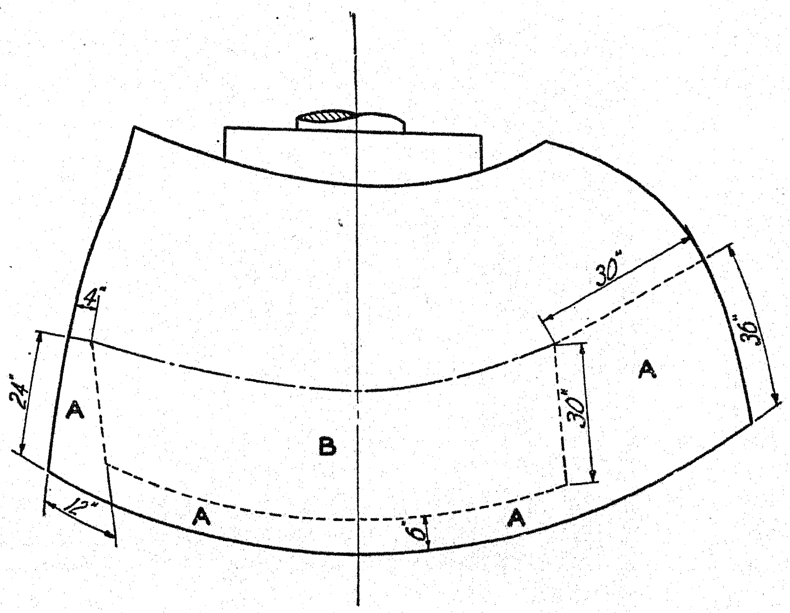

Fig. 4. Prewelded areas on suction face of turbine blades.

machined $\frac{3}{16}$ of an inch below the finished blade surface. Before welding was started, the ridges were ground off so that the entire area to be prewelded was $\frac{3}{16}$ of an inch below the desired finished surface. Any flaws in the castings were chipped out to solid metal and repaired with a mild steel welding rod.

To prevent warpage during welding of the relatively thin blades, varying from 1 inch to $3\frac{1}{2}$ inches in thickness, they were placed in a water bath, so that only the portion of the blade to be welded was out of the water. The water was kept circulating by an electric fan, causing the heat to be carried away as rapidly as possible from the point where the welding was being done. This rapid cooling not only reduced warping but also reduced grain growth in the welding deposit to a minimum. This was of particular importance since the research carried out previously showed increasing pitting resistance with decreasing grain size.

In order to weld the periphery, the blades were held vertically and rotated as the welding progressed so that the welding could be done in the horizontal. All of the welding was done electrically using $\frac{5}{32}$ inch coated electrodes. A double layer of deposit was applied throughout. Approximately 1800 pounds of electrodes were required for the five blades.

After the welding operation was completed, the blades were checked for shape. It was found that very little distortion had resulted from

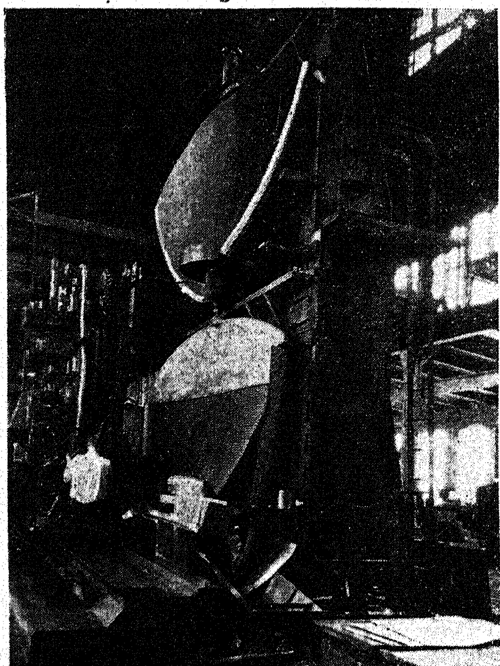

Fig. 5. Machining prewelded blade. Photo courtesy, S. Morgan Smith Co.

welding and there was no difficulty in springing them back into shape.

The blades were then mounted for machining as shown on Fig. 5. It was found that the welded areas could be machined practically as fast as the parent metal areas. The quality of welding was excellent and there were only a few rare instances when it was necessary to do any patch welding. The round nose cutter left ridges which were ground off and then the surface was carefully polished. The finished blades assembled in the hub are shown on Fig. 6. In this picture the prewelded areas show up somewhat lighter than the parent metal.

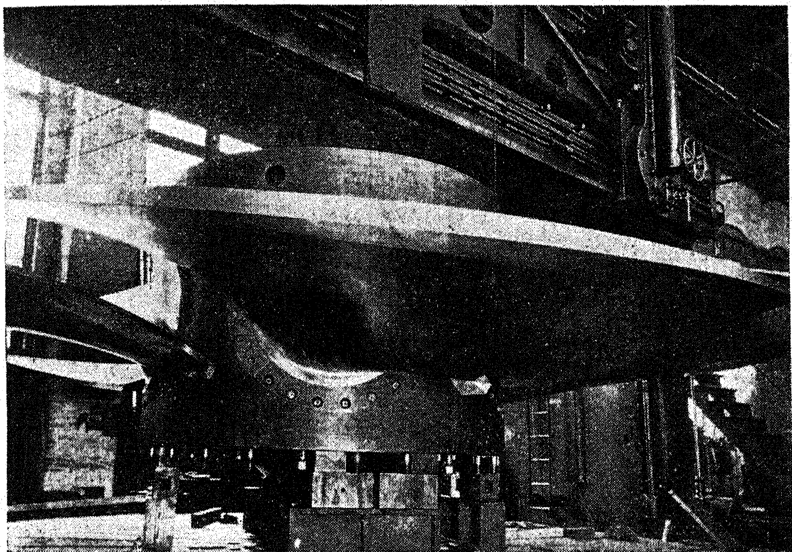

Fig. 6. Finished prewelded runner blades mounted in runner hub.

Metallurgical and Economic Aspects of Prewelding.—While prewelding with stainless 18-8 chromium nickel steel electrodes proved advantageous for the new Safe Harbor unit, it should be recognized that for other installations welding electrodes of a different type may be considered. For instance where machining of the runner blades should also impose some limitations on hardness of the welding deposit and where cavitation is expected to be more severe than at Safe Harbor, an austenitic 18-8 chromium nickel steel alloyed with 3 per cent molybdenum will result in a deposit of higher pitting resistance and may give adequate service. On the other hand, where machining is not required and therefore no limitations are set on the original hardness of the welded areas except with a view to grinding, and at the same time very severe cavitation conditions are expected, austenitic 17-7 or 16-6 chromium nickel deposits, or one of the stainless chromium variety could be chosen to advantage.

With stainless chromium steel electrodes, however, containing 12 to 14 or 18 to 20 per cent chromium and with or without small additions of nickel, some precautionary measures should be taken to prevent

the formation of hair cracks or zone cracks. These cracks occur due to the air hardening characteristics of this alloy group. Based on field experience, areas built up with representatives of this group, and in service over a period of years at Safe Harbor, it may be concluded that neither hair nor zone cracks are conducive to pitting. Certain objections may, however, be raised from a structural point of view, particularly with respect to the deeper zone cracks, and both types of defects are undesirable from a manufacturing standpoint. These im-

TABLE IV.—COMPARATIVE COST INDEX OF SOLID CAST AND PREWELDED TURBINE BLADES FOR FIVE BLADE PROPELLER TURBINES OF THE FIXED BLADE OR THE KAPLAN TYPE

Type of Blade Material	Specification for Blade Material								
	C	Mn	P	S	Si	Ni	Cr	Mo	V
Cast Carbon Steel	.30▲ .40*	.60▲ .80*	.035*	.035*					
Cast Low Carbon Stainless Chromium Nickel Steel	.07*	.50*	.035*	.035*	.50*	6.0▲ 7.0*	16.0▲ 17.0▲		
Cast Stainless Chromium Nickel Steel	.25*	.50*	.035*	.035*	.50*	6.0▲ .70*	16.0▲ 17.0*		
Cast Stainless Chromium Steel	.12*	.50*	.035*	.035*	.50*	1.0▲ 2.0*	11.5▲ 13.0*	.40▲ .60*	.10*
Cast Carbon Steel prewelded with Stainless Steel	.30▲ .40*	.60▲ .80*	.035*	.035*					

Type of Blade Material	Cost of Turbine Blades in Percent of Cast Finished Ground Carbon Steel Blades			
	Runner Diam. 220 in.		Runner Diam. 100 in.	
	Finish Ground	Machined and Ground	Finish Ground	Machined and Ground
Cast Carbon Steel	100	146	100	150
Cast Low Carbon Stainless Chromium Nickel Steel	280	340	240	300
Cast Stainless Chromium Nickel Steel	250	312	210	267
Cast Stainless Chromium Steel	220	283	185	242
Cast Carbon Steel prewelded with Stainless Steel	136	193	140	195

▲ Minimum * Maximum

perfections can be prevented firstly by keeping the carbon content low, that is, below .08 per cent, and secondly, by depositing on the parent metal an insulating layer of stainless 18-8 chromium nickel steel. This layer not only prevents the infiltration of carbon, but due to its excellent ductility it may stretch or contract along the two boundaries that are adjacent to the parent metal and the stainless chromium steel top layer, respectively.

The economic considerations of prewelding are of fundamental importance. Taking advantage of recent progress in the casting of stainless steel in this country, actual quotations were obtained from several turbine manufacturers on solid cast stainless steel blades, to be compared with present costs of prewelding.

These cost data in index form are presented in Table IV. Relative values were chosen rather than absolute to preserve the usefulness of this table, even if material and labor cost should vary. It is true that a variation of these factors may change the index figures to some extent, but it is reasonable to assume that this change may be only of very minor proportion, changing the economic aspects little, if any.

Three types of stainless steel castings were given consideration. The selection was made based on the results of an exhaustive laboratory research on the pitting resistance of cast stainless alloys. For the austenitic chromium nickel steel castings, chromium and nickel were kept on the low side to obtain an ultimate of hardening under cold working. To improve the hardness of the stainless chromium steel, 1 to 2 per cent of nickel was specified, while molybdenum and vanadium serve as essential grain refining agents. No differentiation was made regarding the various stainless electrodes which may be given consideration, because the price range is rather narrow and in actual practice it is likely that identical base prices may be obtained. It was assumed further that somewhat more than 50 per cent of the suction face of the propeller blades are to be prewelded, all of the peripheral blade surfaces, as well as the entire trailing edges. (See Fig. 4).

From Table IV it is evident that for a 220 in. diameter runner with today's index base of 100 for 5 cast and finished ground blades at $21,000, the saving by means of prewelding amounts to $17,500 over cast stainless chromium steel blades, $24,000 over cast stainless chromium nickel steel and $30,000 in the case of low carbon stainless chromium nickel steel. The corresponding savings for machined and ground blades for the same runner diameter are $19,000, $25,000 and $31,000, respectively.

From the trend of the index figures, it may be noted that the economic aspect varies with the runner size. While with decreasing runner diameter a point may be approached for very small turbines where cast chromium blades may be as economical or even less costly than prewelded runners, the increasing advantage of prewelding is apparent for larger size units than those mentioned on the table. For five blade runners of 260 to 280 inches diameter, such as are now being manufactured or installed at hydroelectric developments under construction in this country, the respective savings should be 40 to 50 per cent above those determined for the 220 in. runner.

Conclusions.—Prewelding as developed for this large capacity low head turbine of the propeller type has been found entirely feasible in manufacturing and satisfactory in service. A recent inspection, after three years of continuous service, showed that the prewelded areas were undamaged even at the points most exposed to cavitation. Some minor pitting did occur on the unprotected parent metal inside the 6 inch peripheral band and also on the trailing edge. For this reason the prewelded areas should be enlarged as indicated on Fig. 4. This enlarged area was used as a basis for the economical aspect presented in Table IV.

For large size propeller type runners, the metallurgical advantages of prewelding are of great importance from a manufacturing point of view, as the process does not involve any difficulties such as may be encountered in course of production of solid cast stainless steel blades to obtain the utmost in pitting resistance of the blade surfaces. Due to the very nature of the welding process, the conditions are ideal to obtain an economical and satisfactory protection provided proper welding electrodes are used and at least two coats are deposited. The experimental installation for Safe Harbor has been so successful that prewelding of the turbine blades was specified for the large turbine runners manufactured during 1937 to be installed at the Bonneville Navigation Power Project and the Pickwick Landing Dam. These units will be placed in operation sometime during 1938. At this time prewelding of turbine blades is being considered for the Kaplan units to be installed at the Chickamauga and Guntersville developments. It is obvious that the method of prewelding may not only be limited to turbines, but may also be used to advantage for large propeller pumps and ships' propellers.

In view of the above, it is also evident that prewelding of large propeller turbines shows substantial economical advantages over solid cast stainless steel turbine blades. At the same time, many of the arguments in favor of the solid cast stainless steel blades are also valid for prewelded runners. Properly prewelded runners are neither subject to aging nor are their efficiency characteristics impaired with time. Furthermore, prewelded runners likewise need no periodic repairs, increasing thereby the utilizing factors of the plants, particularly where more water is available throughout the year than is required for station use. Although difficult to evaluate, this factor alone may be responsible for millions of kilowatt-hours of additional generation by the industry as a whole and thousands of dollars of revenue may be obtainable which otherwise would be lost. In addition, no limitations need usually be imposed on the load carried by a prewelded unit to reduce the draft and thereby the velocity of the water to minimize the effects from cavitation, a procedure found necessary on unprotected carbon steel runners. Here again substantial benefits may accrue to the industry through additional energy made possible by means of prewelding.

Chapter VIII—Prime Movers Constructed Throughout by Electric Arc Welding

By Henry F. Gauss,
Professor, mechanical engineering, University of Idaho, Moscow, Idaho.

Introduction.—It is the purpose of this discussion to set forth as clearly as possible the procedure and methods by which ordinary reciprocating prime-movers, both steam and gas, may be constructed throughout by arc welding with a resultant reduction in labor and cost and an improvement in the final product.

The mechanical engineering students at the University of Idaho work on practical projects in their shop courses. These projects consist of the design and building of steam engines, diesel engines, gasoline engines, and other machines having applications in industry. It is not the fundamental purpose of these courses to develop tradesmen, and the fact that the function of the engineering college is to train men to become professional engineers is kept constantly in mind; at the same time many of the students develop remarkable manual skill and dexterity which is certainly a great asset from a design and production standpoint.

The mechanical engineering department recently secured an arc welding outfit from the United States Navy, which it was possible to put in first-class condition and which has become a real asset. Due to the expense of having the castings made for the aforementioned two-cycle engine, the writer set about to re-design the engine so that it could be made entirely of welded construction. An account of the design, its execution, and a comparison of the arc welded engine with the cast metal one are given in the following discussion.

Two-Cycle Engine of Alloy Steel Arc Welded Throughout.—It was desired to design and build a single cylinder, two-cycle engine of about two horsepower. Before beginning the detailed design, the writer secured a number of catalogs and descriptive pamphlets from the manufacturers of small cast metal two-cycle gasoline engines. The idea was to profit as much as possible by the experience of others and to produce an engine of proportions representing good engineering practice. The compression ratio, the ratio of bore to stroke, the piston displacement, the piston speed, and the size of the inlet and exhaust ports were points which had to be decided upon at the outset. With the aid of the experience and information available, the following specifications were adopted:

GENERAL SPECIFICATIONS

Horsepower	2
R.P.M.	3000
Bore	2¼″

Stroke	1¾″
Inlet Port	⅜″ high x 2″ wide
Gross Area Inlet Port	0.75 sq.″
Net Area Inlet Port	.469 sq.″
Exhaust Port	½″ high x 2″ wide
Gross Area Exhaust Port	1 sq. in.
Net Area Exhaust Port	.625 sq. in.
Compression Ratio	1:6

The manufacturing procedure described applies to the fabrication of one engine only and is not intended to apply to quantity production. For quantity production, some of the procedure as described could be followed, but most of the pieces entering into the assembly would be stamped or pressed in permanent dies, and permanent jigs and fixtures would be provided for expediting the arc welding. Due to the fact that the arc welding machine owned by the department is an old model, the actual welding could not be made to look as neat as is possible with recent machines. The project is presented to illustrate a unique application of arc welding to a very practical and valuable product both simplifying and improving it as well as greatly reducing the cost of manufacture.

The success of arc welding operations in assembling the kind of machine considered in the present paper depends largely upon the order in which the various parts are assembled. Often serious difficulty can be avoided by proper attention to this fact. In the present discussion the various operations are described in the order found most desirable to facilitate the fabrication of the engine.

The Cylinder, Water Jacket and Upper Half of Crankcase.—The cylinder, water jacket, and upper half of the crankcase are all assembled as a unit. The material of which the cylinder proper is made is cold rolled steel plate ¼″ thick and has the following specifications recommended by the International Nickel Co., Inc., corresponding to S.A.E. 3140:

Carbon	Manganese	Nickel	Chromium
.35/.45%	.60/.90%	1.00/1.50%	.45/.75%

A thickness of ¼″ is used for the cylinder material with the intention of allowing $\frac{1}{16}$″ for boring leaving a working thickness of $\frac{3}{16}$″ for the finished cylinder and providing sufficient material for future reboring.

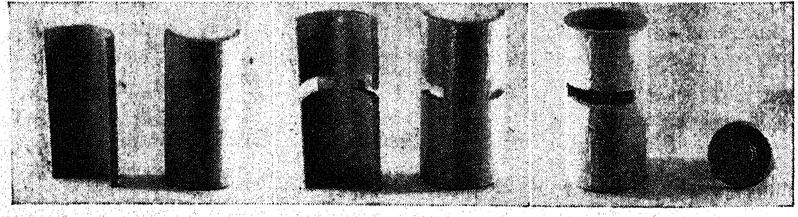

Fig. 1, left, cylinder halves; center, cylinder halves with slots for ports; right, cylinder halves welded together and head end counterbored for cylinder head at right.

The cylinder is made in two halves hot pressed in dies. Fig. 1, left, shows the two halves of the cylinder. The long edges of the cylinder halves are planed in a shaper to produce perfect semi-circular sections and beveled for welding. The inlet and exhaust ports are cut out in a milling machine. Half of each port is cut in each cylinder half respectively. The completed halves ready for welding are shown at center in Fig. 1, and Fig. 1, right, shows the cylinder after the welding has been done.

A short wooden cylinder $2\frac{3}{16}''$ in diameter by 1″ long in each end of the steel cylinder while welding, is of material aid in holding the parts in accurate alignment. The welding is done so quickly that the wood does not have time to burn and can be easily removed after the welding is complete or after the halves have been tacked together.

Bridges in the ports, to prevent the piston rings from catching on the port edges, are now welded in position. It might be stated at this point that the only difficulty encountered in building the engine arose in attempting to insert these bridges. After some experimenting, it was found that the simplest way to do this is to proceed as in Fig. 2, left. The port edges are first beveled at the points at which the bridges are to be inserted. This is conveniently done in a milling machine. Pieces of ¼″ plate are then made in the shape of slightly tapered wedges and driven lightly into the port at the respective bridge locations, care being taken not to distort the cylinder. The outer faces of the wedges are driven slightly below the external surface of the cylinder so that the welding may be entirely across the face of each bridge, thus insuring a strong continuous weld. To aid in holding the steel

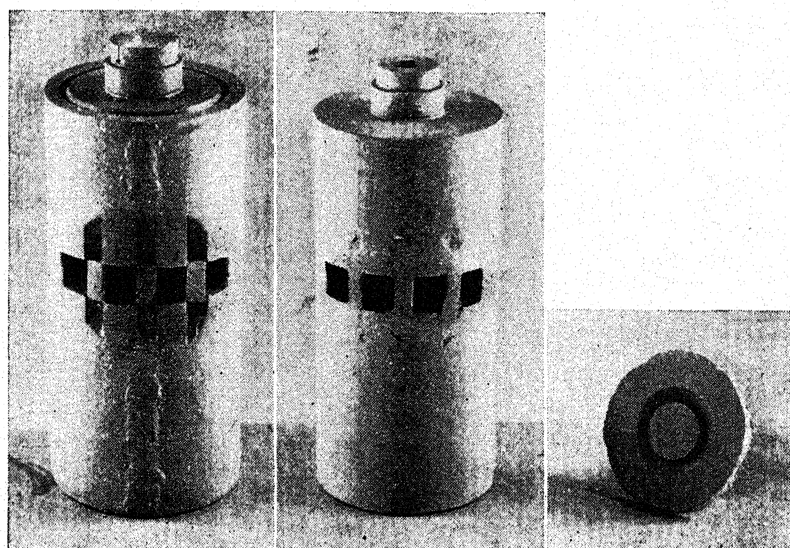

Fig. 2, left, ports beveled for welding bridges and bridges in place ready for welding; center, cylinder head and bridges welded in place; right, rough cylinder head with stud in place ready for welding.

wedges in place during the welding operation, hardwood wedges are fitted between them and driven snugly in place. The bridges are thus successfully welded in place, and the projecting ends are cut off easily by turning and boring in a lathe, leaving a neat substantial bridge in the port opening. Fig. 2, center, shows the cylinder shell after the bridges have been welded in the ports.

The cylinder head is made of the same material as that used for the shell. A disc of 1/4" plate, having an outside diameter slightly larger than the inside diameter of the cylinder, is first cut out by means of a cutting torch. A hole 7/8" in diameter is drilled in the center of this rough disc and countersunk on one side for welding. A short steel stud 1" in diameter shouldered to 7/8" diameter on one end is inserted into the hole in the disc, as can be seen at right in Fig. 2. The welding is then done over the end of the stud and a fillet on the inside avoided. The disc is centered in a lathe by gripping the projecting stud in the chuck, turned down to the inside diameter of the cylinder shell, and beveled on the stud side at about 45° for welding. The cylinder head, at this stage and ready to be welded in the shell, is shown at the right of the shell in Fig. 1, right. The head is placed in the end of the cylinder shell, the short 1" stud on the outside as shown at left in Fig. 2, and welded in place. After welding, the cylinder is chucked in a lathe, carefully centered, and a light truing cut taken over the projecting stud. The stud is cut off and shouldered so that it is long enough to extend through the water jacket space and the outside water jacket head. An axial hole 1/4" in diameter is then drilled through the stud to mark its center which is drilled out and tapped for the spark plug after the water jacket has been welded in place. The cylinder at this stage is shown at center in Fig. 2. A slight counterbore in the head end of the cylinder aids materially in aligning the head for welding. This counterbore is plainly visible in Fig. 1, right. It may be observed by examining Figs. 1, right, and 2, left, that the outer end of the stud in the cylinder head was shouldered for insertion in the water jacket head before the cylinder head was welded in the cylinder. It was afterwards decided that the best method of procedure was to shoulder the stud for this purpose after the head had been welded in the cylinder, and the description of the fabrication assumes this procedure.

The ducts connecting the inlet port with the crankcase and the exhaust port with the exhaust pipe are made of 1/8" cold rolled steel plates containing 1 1/2% nickel and arc welded to the cylinder in their proper locations as shown at left in Fig. 2. Care must be used not to restrict the area of these ducts as the successful operation of two-cycle engines depends to a large extent upon the freedom with which the fresh fuel mixture can enter the cylinder and the exhaust gases leave. The fabrication of these ducts is of interest and will be described in full detail.

The material for the inlet duct is shown unassembled in Fig. 3 and consists of a piece of cold rolled nickel steel plate marked (a) 1/8" thick, 3 1/2" long, and 3" wide; two pieces of 1/4" round iron 3 1/2" long marked (b-b), two pieces of 3/16" round iron 3 1/2" long marked (c-c) and one bent piece of 3/16" round iron 2 1/2" long, marked

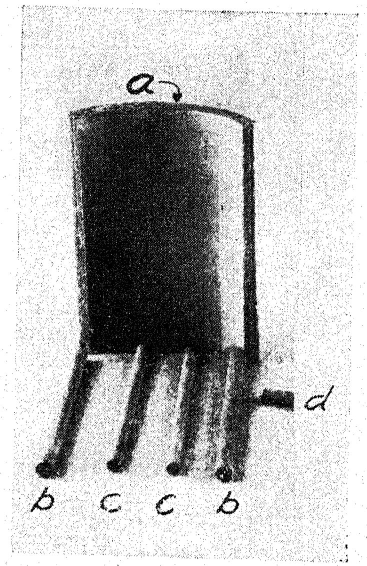

Fig. 3. Material for inlet duct leading from crankcase to inlet port.

(d). The plate (a) is formed in a semi-cylindrical shape with an inside radius $\frac{3}{16}''$ greater than the outside radius of the cylinder, the long side of the plate being parallel to the axis of the cylinder. The plate is placed over the inlet port and extends to the base of the cylinder. The two pieces of $\frac{3}{16}''$ round iron $3\frac{1}{2}''$ long are spacers to hold the plate at the proper distance from the cylinder during the welding process. The $\frac{1}{4}''$ rods are laid in the openings between the cylinder and the vertical edges of the bent plate and welded to the plate and the cylinder. The $\frac{3}{16}''$ spacers are removed, after the welding is com-

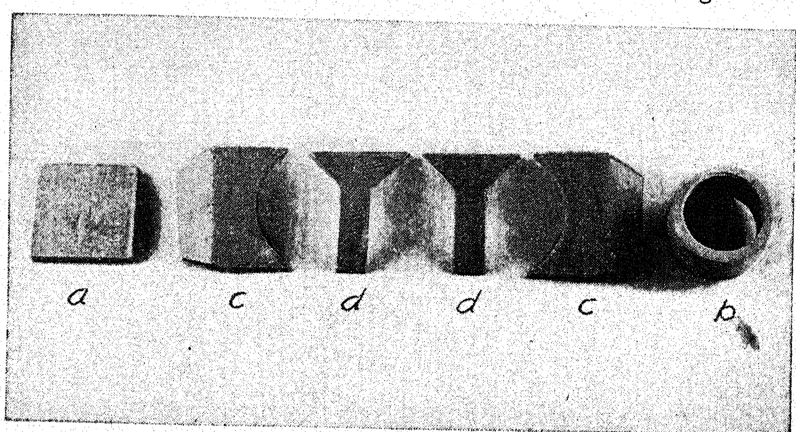

Fig. 4. Material for duct forming transition between rectangular exhaust port and circular exhaust pipe.

plete, and the $\frac{3}{16}'' \times 2\frac{1}{2}''$ bent rod is fitted into the opening between the upper end of the bent plate and the cylinder just over the port. The rod thus fitted is put in place and welded. The result is a very satisfactory inlet duct leading from the crank end of the cylinder to the inlet port.

The duct connecting the exhaust port with the exhaust pipe is more complicated than the inlet duct because it must form a transition from the rectangular port to the round exhaust pipe. The material for the exhaust duct is shown unassembled in Fig. 4. First a plate $1\frac{11}{16}'' \times 1\frac{11}{16}'' \times \frac{1}{8}''$ thick marked (a) is welded over one end of the 1" pipe coupling or sleeve marked (b) in the figure. Two bent plates marked (c) are made, one end of each being fitted to the cylinder, the other ends to the square plate (a). These bent plates form the top and bottom of the transition. Two bent plates marked (d) in the figure are made for the sides and fitted between the top and bottom plates previously made. The assembly is then welded together forming the desired transition.

A wooden form cut to the shape of a core for the assembly can be readily sawed out on the band saw and the parts of the transition clamped around it for welding after which the wooden core can be burned out. The writer was able to assemble the transition described in the present article without the aid of the wooden core, but such a core would aid in the work considerably. A one-inch hole is drilled

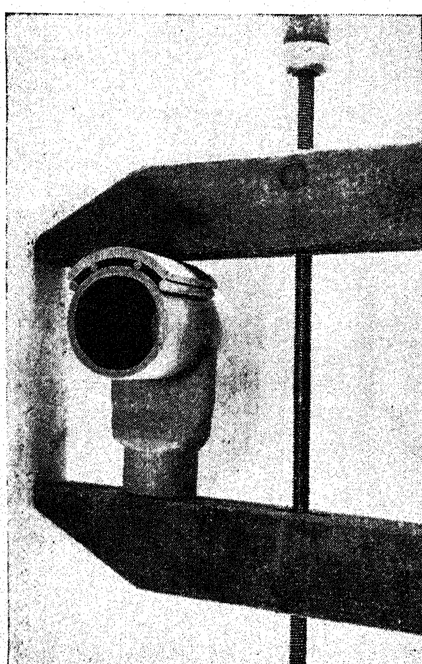

Fig. 5. Inlet and exhaust ducts clamped in position ready to be welded to cylinder.

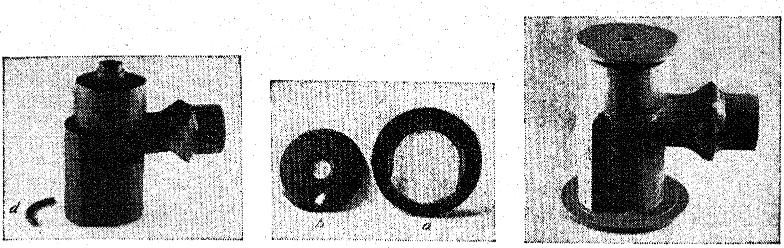

Fig. 6, left, inlet and exhaust ducts welded to cylinder; center, plate forming base of cylinder and connection between cylinder and upper half of crankcase; right, cylinder base and top of water jacket welded in place.

through the square plate welded to the 1-inch pipe sleeve, co-axially with the pipe sleeve after the transition is assembled.

Fig. 5 shows the inlet and exhaust ducts clamped in position ready to be welded to the cylinder as shown at left in Fig. 6. The $\frac{3}{16}''$ round bent rod provided to close the opening between the cylinder and the upper end of the inlet duct is shown to the left of the cylinder in Fig. 6, left.

A circular plate $\frac{3}{16}''$ thick forms the base of the cylinder as well as the connection between the cylinder and crankcase. This plate is shown at center in Fig. 6, and marked (a). The center of the plate is cut out to fit the contour of the base of the cylinder. Fig. 6, right,

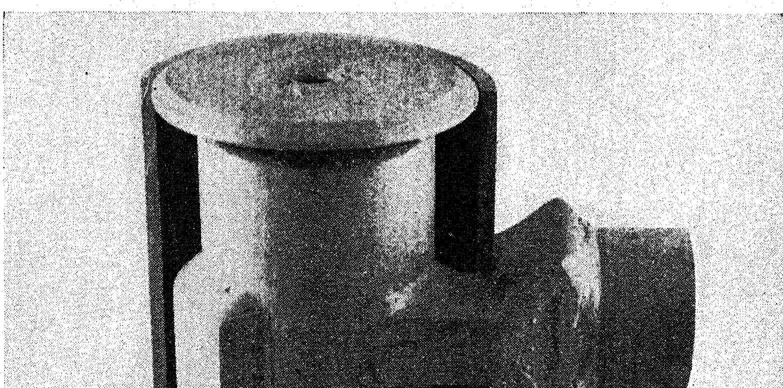

Fig. 7. Half of water jacket shell in position around cylinder.

shows the base welded to the cylinder. It will be observed that the outer portion of the cylinder side of the base plate is faced down leaving the central portion raised slightly. The purpose is to center the water jacket easily and insure a uniform depth of cooling water around the cylinder.

The top of the water jacket shown at (b) in Fig. 6, at center, consists of a ⅛″ circular plate the outside diameter of which is the same as that of the raised portion of the base plate. A ⅞″ hole is bored in its center to fit the shouldered part of the short stud projecting from the cylinder head. The edges are beveled for welding and the plate is placed in position over the cylinder head and welded to the stud. Fig. 6, right, shows the cylinder after the water jacket top has been welded in place.

The shell of the water jacket is made in two halves in a manner similar to that used in making the cylinder. Each half is cut out to fit the exhaust duct, then placed in position around the cylinder, centered in the depression in the circular base plate afore-mentioned as shown in Fig. 7, and welded at all joints.

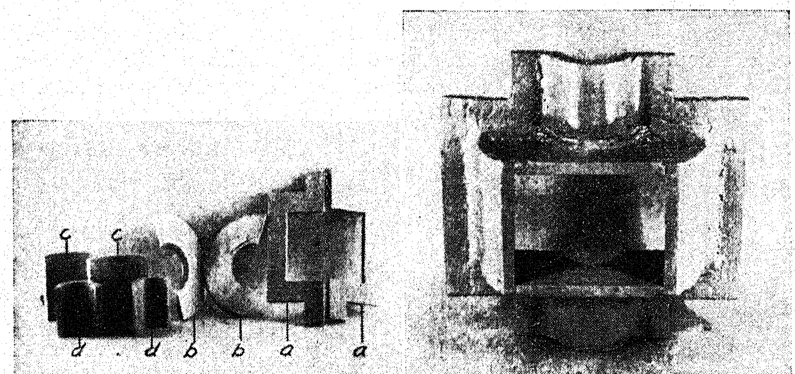

Fig. 8, left, parts of upper half of crankcase; right, upper half of crankcase assembled.

The upper half of the crankcase is shown at right in Fig. 8. It is made of 5/16″ steel plates shown unassembled at left in Fig. 8. (a-a) are flanges, (b-b) are semi-circular ends, (c-c) are semi-cylindrical sides, (d-d) are upper halves of the bearings. The proper size and accurate shape of the crankcase are secured by means of a form made of wood. The plates are assembled around it and tacked together at the corners. The form is then removed and the welding is completed.

The crankshaft bearings are made in halves, hot pressed from ¼″ plate with sufficiently large bore to permit proper babbiting. Half of each bearing is attached to the upper half of the crankcase, and half to the lower half of the crankcase, respectively. Before assembling the crankcase, the halves of the crankshaft bearings, (d-d), are welded to the flat semi-circular ends, (b-b). This order is to permit the welding to be done on the inside and outside which produces a strong and good-looking exterior.

The upper half of the crankcase is now placed in position over the base of the cylinder, clamped securely, and welded to the circular plate, the welding being done from the outside.

The engine is horizontally split through the center line of the crankshaft. This has important advantages as far as construction and maintenance of the engine are concerned, but it imposes the necessity of maintaining a tight joint between the crankcase halves in order to obtain sufficiently high crankcase compression for scavanging and to prevent the loss of fuel mixture. This requirement is easily met with proper attention to the workmanship at this point.

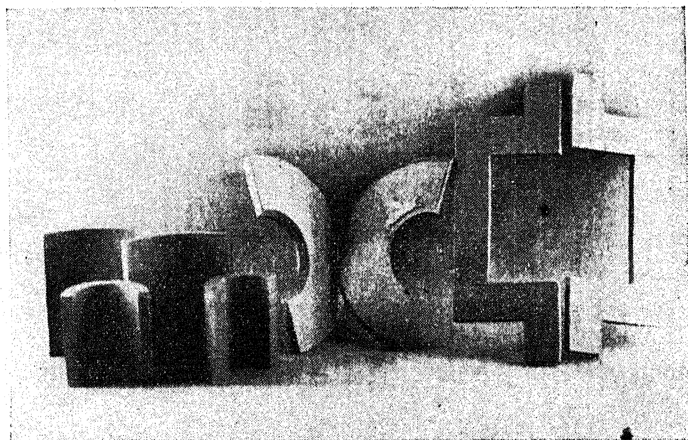

Fig. 9. Parts of lower half of crankcase.

The Lower Half of the Crankcase.—The lower half of the crankcase is composed of the parts shown in Fig. 9. The same form used for assembling the upper half of the crankcase is used in assembling the lower half. Thus, a perfectly symmetrical section is secured, as well as good alignment of the two halves. At this state, the appearance of the lower half of the crankcase is the same as that of the top half, shown at right in Fig. 8.

A rectangular plate $\frac{3}{16}''$ thick provided with a circular hole in its center forms the bottom of the lower half of the crankcase and is shown welded in position in Fig. 10. The hole in the center of the plate is designed to receive the inlet valve cage.

The Inlet Valve Cage.—The parts of the inlet valve cage consists of a short piece of 2″ iron pipe, a circular seat, and a rectangular flange. Fig. 11 shows the valve cage attached to the base of the lower half of the crankcase.

The Engine Base.—The base upon which the engine rests serves the two-fold purpose of supporting the engine and providing a convenient location for the carburetor. The air fuel mixture passes from the carburetor into a suitable chamber in the base, thence into the

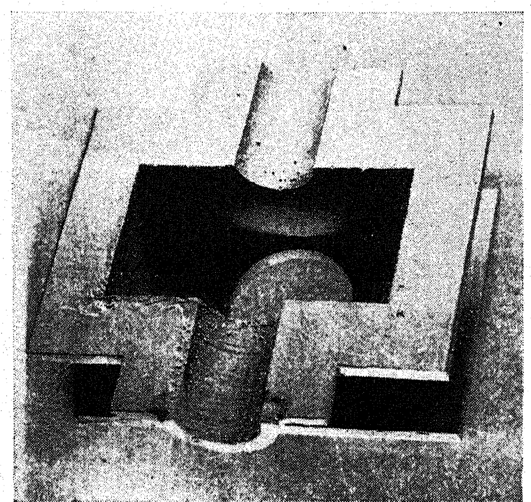

Fig. 10. Lower half of crankcase assembled.

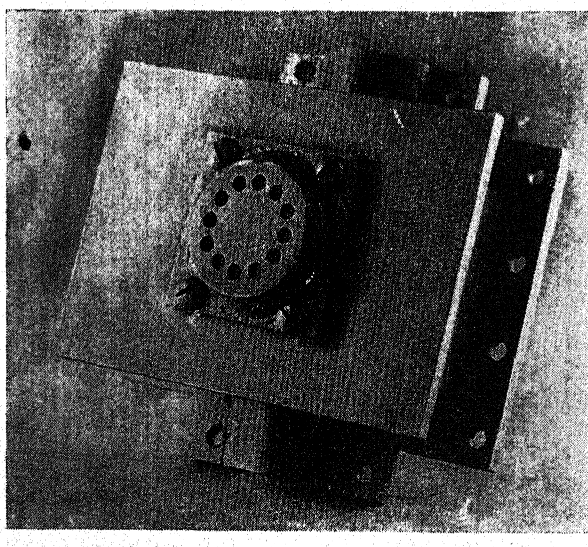

Fig. 11. Valve cage attached to bottom of crankcase.

crankcase through the inlet valve in the bottom of the crankcase provided for that purpose and shown in Fig. 11.

The partially assembled parts of the base are shown at left in Fig. 12. The rectangular plate (a) is the same in size as the bottom of the lower half of the crankcase, and the rectangular hole in this plate fits over the valve attached to the bottom of the crankcase

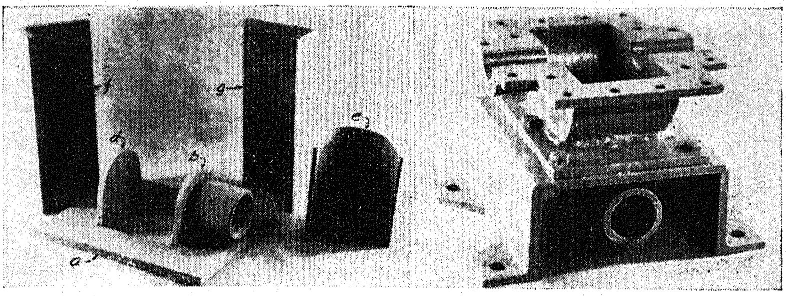

Fig. 12, left, parts of engine base; right, base completed and bolted to lower half of crankcase.

(b) is a U-shaped plate, provided with a hole proportioned to receive a pipe sleeve (c) to which the carburetor is attached. Plate (b) is first welded to the base plate (a), at one side of the square hole therein. Then the pipe sleeve is inserted in the hole in (b) and welded in place. The reason for this order of procedure is obvious. Plate (d) is a U-shaped plate of the same size as (b) but having no holes. It is welded to plate (a) in a position opposite to plate (b). (e) is a cover plate bent to fit over plates (b) and (d) to which it is welded as well as to plate (a). Thus, the chamber in the base plate receiving the air fuel mixture from the carburetor is formed. (f) and (g) are the legs of the engine base. They consist of short pieces of angle iron. Fig. 12, right, shows the base bolted to the lower half of the crankcase.

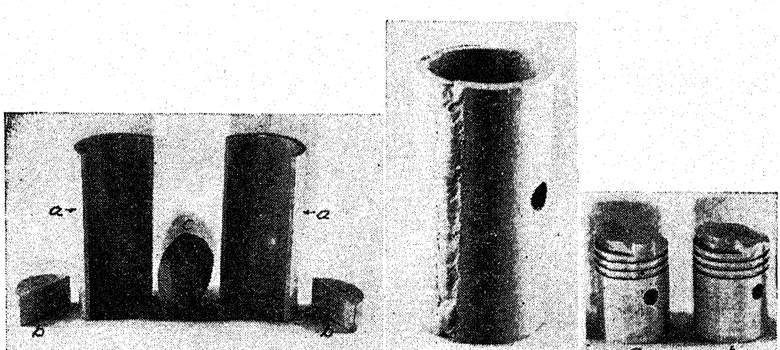

Fig. 13, left, parts of engine piston; center, two cylinder halves welded together; right, completed piston (a), cast iron piston (b).

The Piston.—The engine piston is made from steel plate ¼″ thick, having the same composition as that from which the cylinder is made. The parts unassembled are shown at left in Fig. 13. (a) and (a) are designed to form halves of the cylindrical portion of the piston. They are made from flat rectangular plates, hot pressed in dies. (b) and (b) are re-enforcements for supporting the wrist pin and are to be welded inside of plates (a) and (a) respectively. After welding these re-

enforcements in place, a lead hole is drilled in each to be subsequently bored out for the wrist pin. The two halves are then welded together forming the shell shown at center in Fig. 13. Returning to left, Fig. 13, (c) is the piston head. It is turned from a solid piece of steel, then planed in a shaper to the approximate form required as shown. The top of the piston shell is shaped to conform with the piston head, and the edges beveled for welding, after which the piston head is inserted in the shell and welded. To assist in welding the head in the shell, the shell is first counterbored so that the head can be inserted the proper distance in the shell and held in proper alignment during the welding process.

It would not be good practice to run the steel piston in a steel cylinder having the same composition. Hence, the piston is first machined to within about 8-thousandths of an inch of its finished diameter, the ring grooves are cut about 4-thousandths deeper than finally required and the piston is case hardened. After the case hardening, the piston is ground to its final dimensions. Fig. 13, right, shows the finished piston ready to be inserted in the cylinder.

The piston head is designed to be pressed from 1/8" steel plate in suitable dies. The author did not attempt to construct such dies, but shaped the piston head from a solid plate. For quantity production, the proper procedure would be to make the dies. However, the possibility of making engine pistons entirely by welding is the objective of the discussion, and is well illustrated by the procedure followed. It should also be pointed out that for quantity production it would be good economy to have special rolled plates for forming the piston shell. The author used a flat steel plate for purposes of illustration and bored the skirt out in a lathe to lighten the final product.

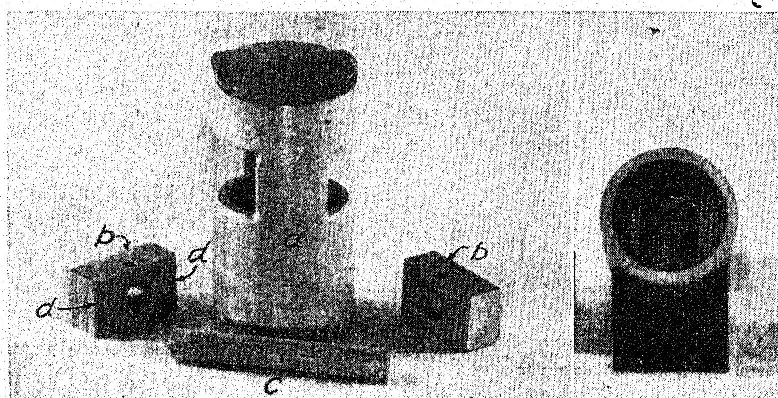

Fig. 14, left, parts of piston made from tube; right, looking into crank end of finished piston.

Alternate Method of Making Piston.—The piston can also be made from a piece of tubing. This complicates the insertion of the re-enforcements for the wrist pin which were welded to the inside of each half when the piston was made in halves. This complication can be met by

the following scheme: The end of the tube is first shaped and counter-bored to receive the piston head as described for the piston made in two halves. From this point the procedure is indicated in Fig. 14, left. (a) is the piece of tubing having the piston head welded in place. (b-b) are re-enforcements for the wrist pin bearings and consist of short pieces of steel of rectangular cross-section. Diametrically opposite slots are milled in the walls of the tube to admit the wrist pin re-enforcements. (c) is the wrist pin. The sides of the slots are beveled for welding and the wrist pin re-enforcements are inserted and welded to the tube. The wrist pin re-enforcements are made slightly shorter than the opening across the flats of the slots milled in the tube. Furthermore, they are relieved at the ends a small amount as shown at (d-d) to facilitate centering them in the slots, and holding them in alignment during welding which is done with the wrist pin in place. It might be pointed out that the reason for making the wrist pin re-enforcements slightly shorter than the opening in the slots across the flats is to provide a junction of parts which will admit effective welding. The tube is finally centered in the lathe and the projecting corners of the wrist pin bearings are turned off. At right of Fig. 14 is a view looking into the end of the piston showing the wrist pin and re-enforcements. The procedure from this point is the same as that used when the piston is made in two halves.

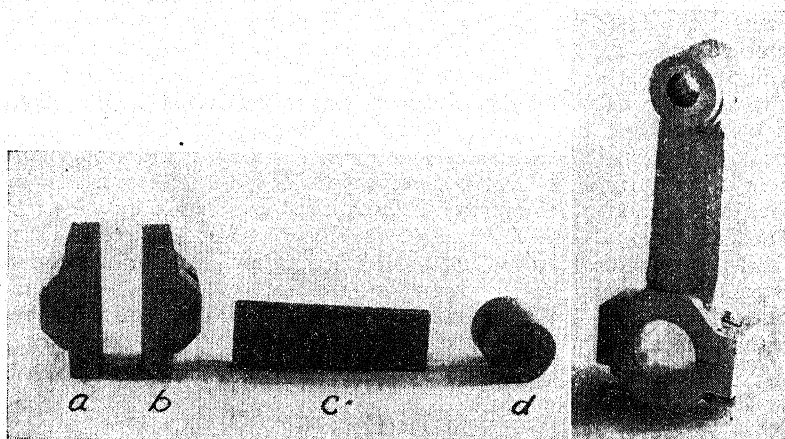

Fig. 15, left, parts of connecting rod; right, finished rod.

The Connecting Rod.—The parts of which the connecting rod is made are shown at left in Fig. 15. (a) is the upper half of the crank pin bearing, and (b) is the lower half. (b) is the rod and (d) is the wrist pin bearing. It will be noted that (a) and (d) are slotted to receive the ends of the rod. This aids greatly in lining the parts up for welding. The complete rod with the crank pin end babbitted and the wrist pin end bronze bushed is shown at right in Fig. 15.

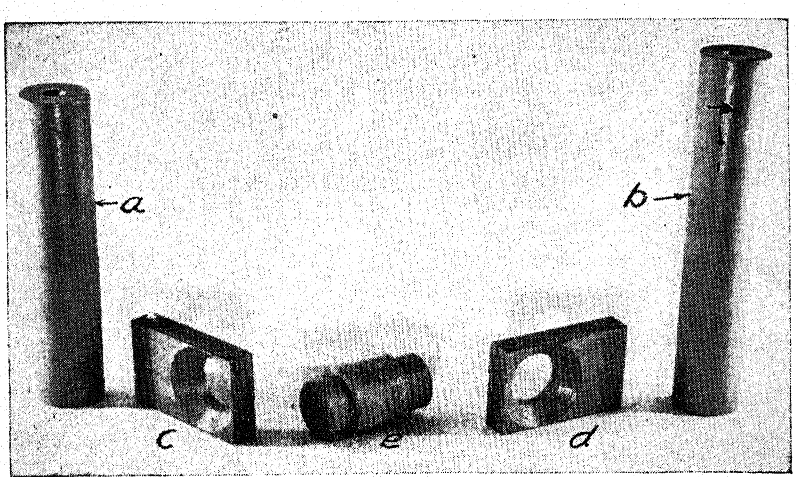

Fig. 16. Parts of crankshaft.

The Crankshaft.—The parts of which the crankshaft is made are shown in Fig. 16. (a) and (b) are the shafts, (c) and (d) are the crank arms, and (e) is the crank pin. A difficulty encountered in making the crankshaft is caused by the fact that the crank pin overlaps the shaft, making it impossible to bore two holes entirely through the crank arms, one for the shaft and one for the pin. This difficulty is overcome by proceeding as follows: a hole is bored entirely through each crank arm to receive the crank pin which is shouldered on each end to facilitate assembly. The holes in the crank arms are beveled on the outer side for welding, and the pin is inserted and welded securely to the arms. The arms thus assembled are chucked in a lathe and a half-inch hole is bored through each co-axially with the shaft. A larger hole is then bored about three-fourths through each arm, co-axially with the smaller holes and beveled to receive the shafts. The crank end of each shaft is turned down and beveled to fit the half-inch holes in the crank arms, the idea being to permit welding the arms to the shafts on both sides. The shafts and crank arms are assembled in a jig and with the crank arms and shafts thus held in accurate alignment, the crank arms

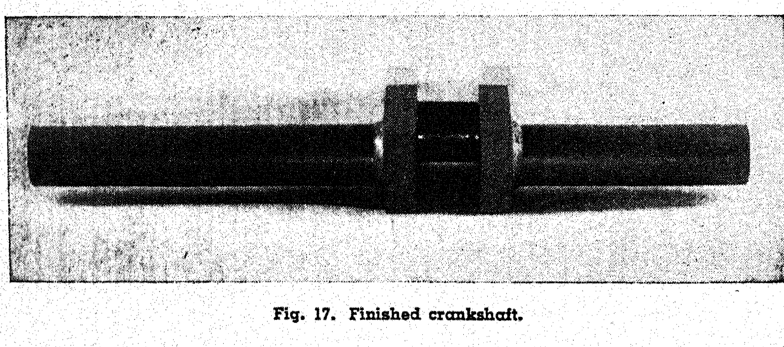

Fig. 17. Finished crankshaft.

are welded to the shafts, both inside and outside. The finished crankshaft is shown in Fig. 17.

Counter Weights.—The counter weights consist of semi-circular iron discs fastened to the crank arms. A suitable disc, three-quarters of an inch thick, is first turned from steel plate. This disc is then cut in half along a diameter and each half is milled out to fit over the crank arms. Allowance is made to insert strips which are welded in place producing the counter weight ready to be attached to the crank arms. The purpose of the strips is to make it possible to attach the counter weights to the crank arms by means of machine screws, thus making it easy to hold them in alignment during the final welding and to eliminate the necessity of extensive welding which might warp the finished shaft. After the weights are attached, the screw heads are spot-welded to prevent them from becoming loose.

Thrust Collars.—The thrust collars consist of steel rings turned and bored and finally shrunk on to the crankshaft in their proper positions.

The Flywheel.—The flywheel consists of a hub, a web, and a rim. The hub is a piece of cold rolled steel shafting one end of which is turned down and shouldered to fit a hole in the center of the web. The web is cut from a piece of steel plate ½″ thick, a hole is bored in its center to receive the shouldered end of the hub which is inserted

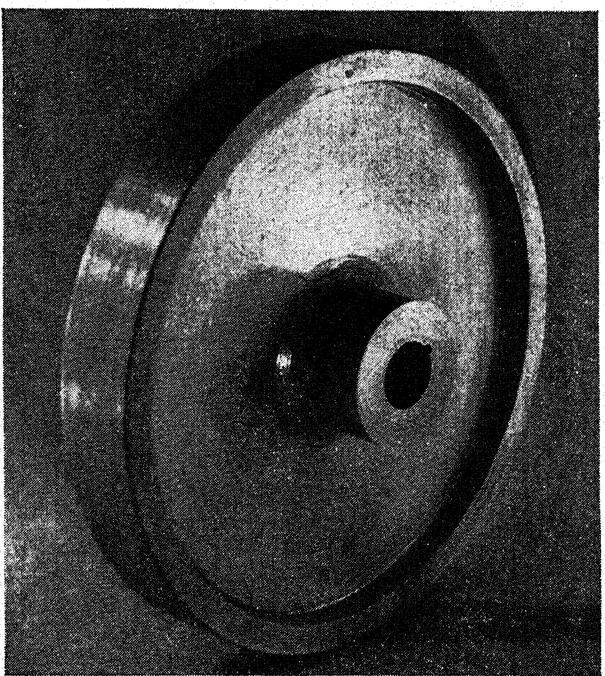

Fig. 18. Completed flywheel.

and welded to the web on both sides. The web is centered in a lathe chuck and the hub trued up and bored to fit the crankshaft. The assembly is mounted on an arbor and finished over its entire surface.

The flywheel rim consists of a piece of ⅝″ x 1½″ steel bar rolled into a circle on a suitable form and of dimensions to permit boring to an inside diameter for shrinking or welding onto the web. The ends of the ring are beveled and welded together. To facilitate the shrinking or welding of the rim on the web, the bore for the fit extends through the rim far enough only to properly center it on the web. The remainder of the bore through the rim is sufficiently smaller to provide a shoulder on which to rest the web when it is inserted in the rim. Fig. 18 shows the completed flywheel with key seat and set screw ready to be mounted on the crankshaft.

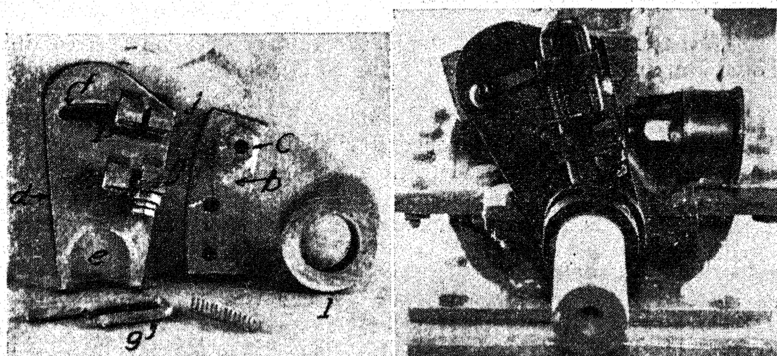

Fig. 19, left, parts of timing device; right, assembled.

The Timing Device.—The timing device is supported by a small "U" shaped bracket welded to the side of the water jacket. The separate parts of which the timing device consists are shown at left in Fig. 19. The plate marked (b) is designed to be attached to the bracket and supports the stud sleeve (c). The plate (d) is provided with a clevis at (e) which slips over the crankshaft, and a slotted hole at (f) which is concentric with the shaft and slips over the stud supported by stud sleeve (c). Plate (d) carries a plunger (g) supported in bearings at (h), (i), and (j), and an insulated terminal (k) with which the plunger makes and breaks contact. The plunger is actuated by the cam (1) which is set screwed on the crankshaft.

The welded details in the timing device are:

1. Plate (b) is welded to bracket (a).
2. Guide bearings (h, i, j) are welded to plate (d).
3. Insulated terminal (k) is welded to plate (d).
4. Stud sleeve (c) is welded to plate (b).

The assembled timing device is shown at right in Fig. 19.

Connection for Carburetor.—The connection for the carburetor is a simple detail. It consists of a flange plate and a short piece of pipe threaded on one end and shouldered on the other for insertion in the beveled hole in the flange plate.

In Fig. 20, the completed engine ready for operation is shown.

Application.—The methods used in the design and fabrication of the engine described in the preceding discussion are applicable in general to all engines of the same type regardless of size. The size and

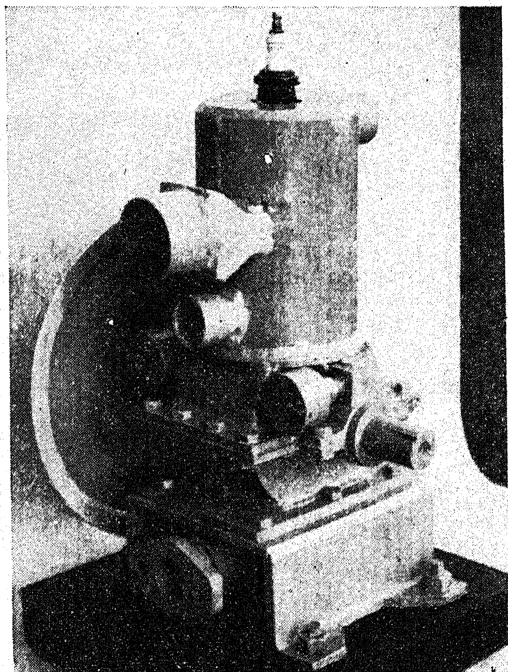

Fig. 20. Completed engine, ready for operation.

design of the engine built made it so well adapted to an outboard drive for a boat that the writer could not resist the temptation to design and build an outboard propeller drive which could be operated by it or any similar vertical engine. The unique feature of the drive as designed is the use of a belt for transmitting the power from the engine shaft to the propeller shaft. A belt thus used must of course, be kept dry. This is accomplished by using pipe or tubing for the main structural members so arranged that the belt is guided through them and thus protected from contact with the water. The belt may be either the flat or "V" belt type. After some correspondence with manufactures of "V" belts, it was decided that due to the reverse bending imposed upon the belt in guiding it through the pipes, a flat belt would have a longer life than a "V" belt. The present design is worked out for a flat belt

drive. Experience might prove that a silent chain would be more desirable than either the flat or "V" belt, and the welded construction would render the necessary lubrication of a chain a simple matter. The extreme simplicity to which the fabrication of a product such as an outboard propeller drive can be reduced by the application of arc welding is well illustrated by the present example.

The design was governed by the following conditions and restrictions:

(a) The drive must be of welded construction throughout.

(b) The belt must be kept dry.

(c) It must be possible to rotate the drive through an angle of 180° about its vertical axis in either direction.

(d) The suspension must permit the drive to swing up should an obstruction in the water be run into.

(e) The assembly must be reasonably light.

(f) The submerged parts must be streamlined and produce a minimum of resistance to motion through the water. The assembled drive is shown in Fig. 21.

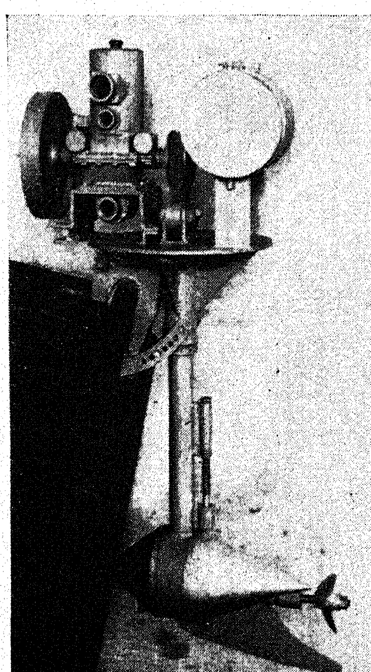

Fig. 21. Arc welded engine as outboard boat power plant.

The Weldability of the Materials Specified.—The discussion, thus far, has concerned itself mainly with the design and arrangement of parts so that the physical operations of welding could be easily performed. The fact that the engine and outboard propeller were actually made as attested by the photographs is evidence of the success of this part of the project. As stated in the introduction, the material used in the construction of the engine built to illustrate the description was common cold rolled steel and iron. The specifications for the steel to be used appearing in the discussion were obtained from manufacturers of steel plates, and the steel plates recommended are known to be suitable for the service imposed and also they are known to be weldable. The proper welding procedure for each type of steel must be followed. This is particularly true of nickel steels. It might naturally be thought that electrodes used in the welding of nickel steels should be of the same composition as the steels themselves. It has been found that entirely satisfactory results may be obtained with a shielded arc mild steel electrode used with reversed polarity in order to secure deep penetration.

It is needless to add that many parts of products such as those described in the foregoing pages can be made of common iron and the more expensive alloy steels should be used only when the service imposed demands it.

The Cost of Welded Steel Construction Compared With That of Cast Iron.—There can be no doubt but that fabrication by welding is much cheaper than construction by casting. This is due primarily to the fact that the amount of material entering into the product is much less when welding is used than when casting is employed.

The casting of a product requires the preparation of patterns, core-boxes, and cores. The moulds must be set up, the metal poured, the moulds torn down, gates and risers cut off the castings and the castings cleaned. The use of machine moulding reduces the manual labor by a certain amount, but it still remains a large item. In addition to allowance for finishing the castings, frequently some draft must be provided to enable the patterns to be withdrawn from the moulds successfully. This draft results in making portions of the castings thicker than necessary so giving rise to a waste of metal. There is always some doubt in a designer's mind regarding the homogeneousness of a cast metal product which causes him to adopt a high factor of safety resulting in the use of more metal than would be required if it were felt that there would be no cavities or blow holes.

The fabricaton of a product from steel plates by welding does not require patterns, core-boxes, cores, and moulds; but it may require special dies, jigs, and fixtures. These may be simple as in the case of the Otto engine described in the foregoing pages or they may be complicated. It is the writer's conviction based on his experience and observation that the cost of the dies, jigs, and fixtures necessary for quantity production by arc welding imposes a smaller overhead burden on the finished product than does the cost of patterns, core-boxes, and foundry equipment on the production of the same pieces by casting.

In fabricating a product by welding, plates of uniform thickness may

be used as the necessity of draft does not enter. Furthermore, since rolled steel plates are homogeneous in structure they are much more dependable than cast material and the designer need not fear to stress them up to their allowable limits.

In building a single article such as the Otto engine the advantage of welding over casting is evident. The cost of building a single engine by casting must bear the entire burden of the patterns, core-boxes, cores, moulds, etc., and is high to say the least. The same engine fabricated by welding costs but a fraction of the cast machine.

To sum up the matter it can be said safely that:

1. The cost of welding the Otto engine described in the foregoing pages is about 50% of the cost of casting it.

2. The gross savings accruing to industry by adopting welding methods in preference to foundry methods is difficult to estimate. From a material standpoint it can be stated conservatively that the welding procedure saves about one-half the material by weight which would have to be used for casting. From a cost standpoint it can be stated that the reduction in price made possible by reduced manufacturing charges results in a wide distribution of the product with the result that the total volume of business on a monetary basis remains the same as when foundry methods were used.

3. The recent improvement perfected in the physical properties of alloy steels have made them particularly desirable for engine parts. Such parts made from these steels are more durable and last longer than when made of cast iron. The reduction in manufacturing cost makes it possible to add refinements which are calculated to improve efficiency and at the same time keep the selling price within reason. Thus the buyer is enable to enjoy the results of greater efficiency which he in turn can pass on to those absorbing his products.

As is well known, the development of the steam prime mover ushered in the industrial revolution with all its benefits to mankind. The development of the internal combustion engine followed the steam engine and has become scarcely secondary in its revolutionary effect on the life of mankind. Prosperity is a function of the power per capita available in a country. Any process which places more power per capita at the disposal of a people by reducing the cost of prime movers and improving their operation makes increased prosperity possible. Unfortunately, other factors and influences enter to interfere with a full realization of this possibility. The prime mover, however, is in no way responsible for this sad state of affairs and stands ready and willing to do its part as soon as society can solve the social and political problems which confront it.

Appendix.—The purpose of this appendix is to describe several modifications in the design of the two-cycle gasoline engine presented in the body of the foregoing discussion. The necessity for making these modifications became evident as this engine was experimented with after its completion.

Carburetor Connection.—It was found that the chamber in the engine base for attaching the carburetor was so large that the sudden

expansion in the air passage connecting the carburetor with the crankcase reduced the velocity of the carbureted air to such an extent that there was a decided tendency for the gasoline to separate out and be deposited in the chamber.

The size of the chamber was reduced and the operation of the engine greatly improved. The reduction was accomplished by setting up the base in a shaper and cutting the chamber off until the sides projected about one eighth of an inch below the valve cage in the lower half of the crankcase. A rectangular cover plate was then welded to the sides and a hole drilled and tapped in its center to receive a $3/4''$ street ell. The carburetor was attached to the street ell and a sufficiently small, direct passage for the air from the carburetor to the crankcase was thus secured. A sleeve was also provided to slip over the circular part of the valve cage and register with the rectangular cover plate, thus, further reducing the tendency for the carbureted air to expand suddenly before reaching the crankcase. The change was simple, easy to make, and effective.

Timing Device.—The timing device described as part of the engine design was intended for battery ignition. It operated satisfactorily but the convenience of magneto ignition, particularly in marine applications, led to the replacement of battery ignition with magneto ignition. No difficulty was involved in making the change and it was not necessary to alter the battery ignition system in any way.

Starting Devices.—The original design of the engine contemplated starting it by turning the flywheel by hand. After completing the fabrication, it was found to be difficult to start the engine by turning the flywheel by hand. Accordingly a starting crank was designed by which it could be spun and which would automatically disengage when the engine fired. The crank consists of a handle, a crank arm, a hub, and a spiral. A stud is inserted in the flywheel at such a distance from the flywheel hub that the inner edge of the spiral engages it when the crank is slipped over the end of the engine shaft and pushed up against the flywheel. When the engine starts it runs ahead of the crank and the spiral pushes the crank out of engagement with the stud, allowing it to hang idly on the end of the engine shaft.

The crank was assembled by arc welding throughout. The most interesting detail was the spiral mounted on the hub. It was made by turning a disc from common iron plate one eighth inch thick, boring a hole in its center to fit the hub, cutting it along a radius; and forcing the sides adjacent to the cut past each other to form a suitable helix or spiral. The spiral was then slipped over the hub and welded to it in several places.

The crank thus made provided a satisfactory means of starting the engine, but in applying the engine to the outboard motor drive it was thought best to provide a pull-rope starter. Accordingly, a sleeve was welded to the outer side of the flywheel co-axially with it. A slot was cut in the outer edge of the sleeve designed to receive the starter-rope and of such a size that a knot in the end of the rope would not slip through it. The sides of the slot were cut on a bias with the axis of the

sleeve so that when the rope, after being inserted in the slot and wrapped around the sleeve, was pulled, the engine would be rotated, and the rope after being unwound would automatically slip out of the slot. A vigorous pull on the rope would spin the engine over several times and no trouble was experienced in starting with the pull-rope starter thus designed.

Pump Push Rod.—After a number of hours of operation, the push rod on the circulating water pump operated by the cam integral with the propeller shaft, was found to be badly worn on the cam end. Ample means for lubricating the contact surfaces had been provided consisting of a hole bored axially into the push rod extending to a hole at right angles to it registering with the outlet from a grease cup provided to lubricate the rod itself. The above wear occurred in spite of this lubrication. To overcome it, a roller was provided in the cam end of the push rod. The same scheme for lubricating it was retained, and no further difficulty due to rapid wear has been observed. The modification, however, entailed the necessity of providing a guide which would prevent the push rod from rotating about its vertical axis and hold the plane of the roller in the plane of the cam on the propeller shaft. This was accomplished by inserting a pin in the upper end of the rod at right angles to it and of sufficient length to engage in a slot milled in a strip of steel welded to the post of the drive.

Steering Rod for Outboard Drive.—In the orignal discussion no mention was made of the handle for steering the outboard drive. It consists of a half-inch round rod welded at one end to a gusset plate which in turn is bolted to the table of the drive. A piece of rubber hose is slipped over the handle end of the rod to prevent any unpleasant vibrations from being transmitted to the operator's hand.

The modifications described in this appendix were easily made, thanks to the process of arc welding. It was unnecessary to discard any parts previously made and no expensive patterns and castings were required. This illustrates the particular value of arc welding in building apparatus used in research work.

While the application of the model two-cycle engine to the outboard motor drive was of interest and attracted much local attention, the fact that the main object of the paper is to discuss arc welding as applied to reciprocating prime movers in general should not be lost sight of.

The two-cycle engine was built for the purpose of demonstrating the feasibility of executing the various designs and welding procedures involved in the discussion. The outboard drive was included because the two-cycle engine built was particularly well adapted to it.

Chapter IX—A Welded Elevator Machine

By JOHN N. ANDERSON,
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In the elevator industry, a manufacturer of elevators must be prepared to furnish machines in sizes ranging from those capable of handling loads of less than 100 lbs., as for small dumbwaiters, to those of sufficient capacity to handle the largest trucks to be found on our highways at the present time. The speeds at which these loads are carried may vary from less than 50 F.P.M. up to 400 F.P.M. for passenger or freight elevators and may be as high as 1,000 F.P.M. or even higher, for passenger elevators.

At the present moment, the great majority of elevators is of the so-called traction type. Briefly, this type of elevator consists of a car supported by ropes which lead up to and over a grooved driving sheave and down to a counterweight. The car is guided by one pair of vertical rails and the counterweight by another pair of rails, both pairs usually being located in the same hoistway. The weight of the counterweight is made approximately equal to that of the car plus 40% of the maximum load to be carried in the car. Normally, the weight of the car will be equal at least to the load in the car and, therefore, sufficient friction, or traction, between ropes and driving sheave will obtain to move the loaded car up or the empty car down without slippage of ropes.

When preparing a line of machines to cover the wide range of duties mentioned, it is essential that the sales and engineering departments co-operate to the end that the sales requirements may be completely covered with as few different machines as is economically possible from a production standpoint.

In conjunction with our sales engineers, a line of machines was planned which would cover all the normal requirements, or duties, which we might be expected to meet. The lower and intermediate duties presented no difficulties in design or manufacture as the sales expectations were of such proportion as to allow any pattern or tool charges to be spread over and absorbed by a great many units. In the highest brackets, however, where the duties to be met comprised very heavy loads at comparatively high speeds, past experience indicated that the demand would be very small and that the pattern and tool expense would have to be spread very thick over each unit sold, thus adding enormously to the factory cost and lowering our competitive advantage to the point where even fewer sales would be made.

Under these unpromising conditions, the task of designing a suitable machine for the unusually heavy loads and high speeds was handed to our department.

It was obvious from the beginning that the machine would have to consist of a rope or driving sheave fastened to a helical gear, both mounted on a shaft carried on suitable bearings and driven by a pinion directly connected to a driving motor. The gear and pinion would be

oil lubricated and run in an oil tight gear case. This machine would operate the elevator through 2:1 roping; that is, the car ropes would lead from the driving sheave down to and under a sheave in the cross-head of the car and up to a dead-end hitch located above, while the counterweight ropes would be similarly attached to the counterweight. It is, therefore, apparent that the speed of the car would be one-half the speed of ropes.

During the years since the advent of the gearless traction elevator, the elevator-riding public has come to regard vertcial transportation as being practically noiseless. They are satisfied to ride to the business centers in busses, trolley cars or subway trains amid noise that renders conversation an impossibility; yet, when they arrive at their offices or stores, they expect their elevators to be smooth and silk-like in operation. This expectation has now spread to elevators of the geared freight type and where, a few years ago, a freight elevator which carried the load up or down in any fashion at all was good enough as long as it ran. Nowadays, any perceptible noise is deemed sufficient cause for complaint. It will, therefore, be understood that in studying and designing the machine which is to be described, no effort was spared in eliminating the possible causes of gear noise.

One well known cause of this noise is slight variation of center distance or of alignment of gears due to deflection of machine parts. To overcome this, we realized that the gear case, which also supports the pinion bearing and one of the bearings of the gear and sheave shaft, would have to be made as rigid as possible without being ridiculously bulky.

A motor which would develop the torque to meet our requirements and a brake suitable for the motor both being available, the sizes of the sheave, gear and pinion were quickly determined and a preliminary design was made on the basis of using iron or steel castings for all the various parts except shafts, pins and the like.

The first design, worked out on this basis, is shown on Fig. 1. This machine consists of a driving, or traction, sheave "A" grooved for hoisting ropes and a single helical gear "B", both mounted on spiders, or centers, which are integral through a connecting neck as shown in section A-A. These spiders and their connecting neck are called the "Gear and Sheave Center", "C", and are arranged on a shaft "D" carried on double-row tapered roller bearings located at the ends of the shaft. The bearings are of special design with a narrow seat on the periphery of the double cup to allow a moderate amount of misalignment and are contained in suitable housings, one of which is part of the gear case, "E" and "F", and the other a part of the outboard bearing stand "G".

The outboard bearing housing is provided with caps or covers "M" and "N" which retain the grease for the roller bearing. This roller bearing is not constrained against end-wise movement in its housing, being left free axially to find its own location.

At the opposite end, the bearing housing is in two halves, one of which is integral with the upper gear case and the other integral with the lower gear case. This bearing housing is provided with an outside cover "J" and an inside half-cover "R" which extends only as far as the

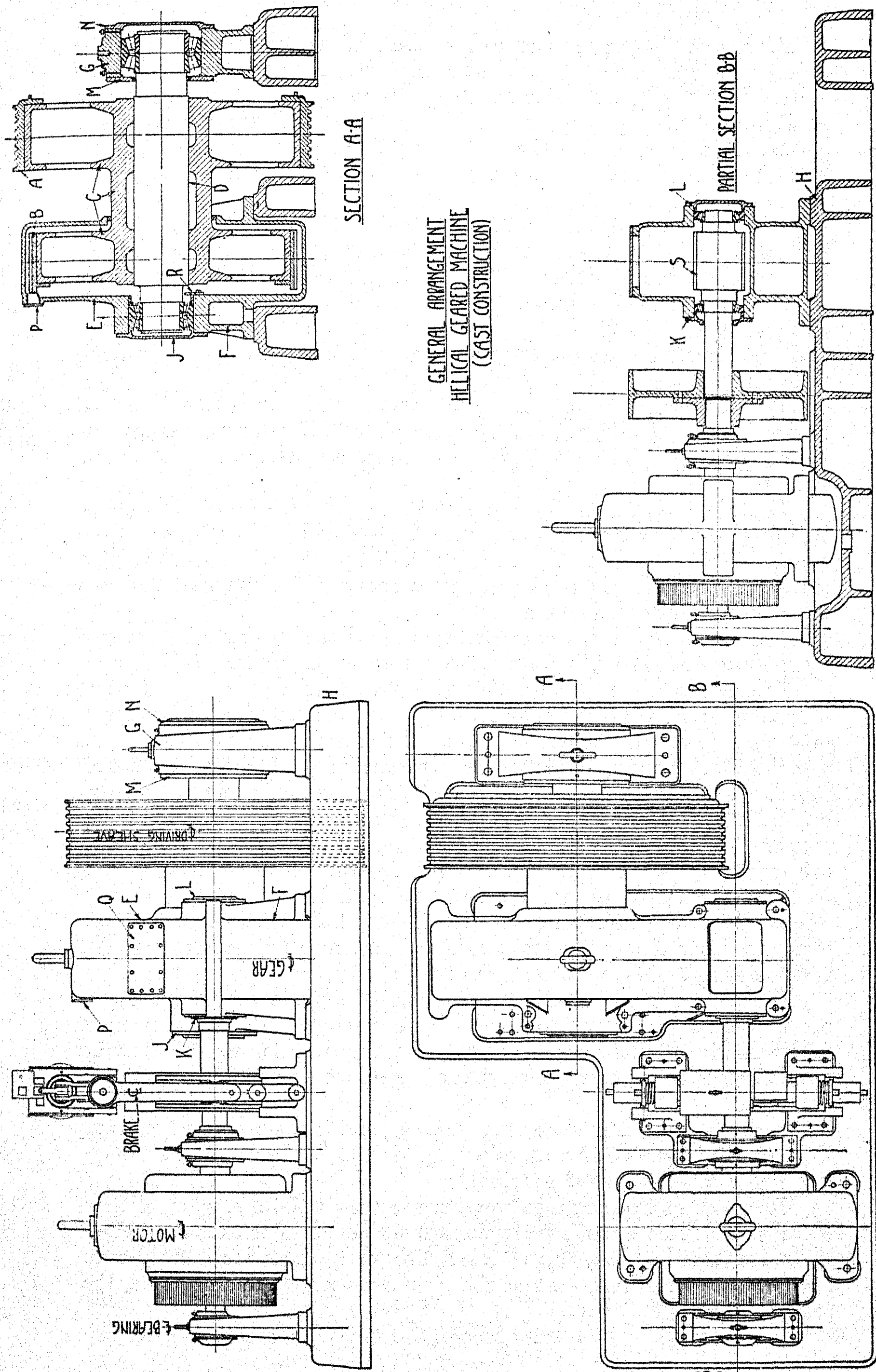

Fig. 1. General arrangement of elevator machine—cast construction.

joint between the upper and lower cases. The thrust, caused by the axial component of the helical gear pressure, is taken by the tapered roller bearing which is located in this housing and is constrained against axial motion through collars and aligning rings with spherical surfaces as shown abutting against the double cup of the bearing and covers "J" and "R". This bearing is supplied with oil provided by a "splash" from the gears.

The cast steel helical gear meshes with a pinion "S" which is supported on single-row tapered roller bearings located closely adjacent to the side of the pinion as shown on Section B-B. These bearings are mounted in housings which are a part of the gear case. Integral with this pinion, is a shaft which extends through one of the roller bearings and is connected to the shaft of the driving motor through a combination brake pulley and coupling.

The outboard stand, gear case, brake stand and motor are all mounted on a continuous cast iron bedplate "H" thus combining the various parts of the elevator driving or hoisting mechanism into a single unit.

The brake used is one in which the shoes, mounted on brake levers, are magnetically released and applied by means of a spring when the magnet is de-energized. Thus the brake is applied when the machine is stopped and released as soon as the current is simultaneously supplied to the motor and the brake magnet.

The foregoing is a rough description of the machine as covered by the first design in which no welded parts were contemplated.

The design of the cast machine, as shown on Fig. 1, was the last of several studies which were drawn up. No detailed working drawings were made but, as will be noted, the study is shown to scale and insufficient clarity to enable a close estimate of works costs to be prepared. These costs covered the complete machine, including motor, brake and sheave, as well as the parts which are given in the following cost analysis and estimate. However, as we are interested in comparing the cast construction with the welded construction as finally adopted, only those parts which are not identical in both designs will be considered. We will, therefore, omit the motor, brake, sheave, roller bearings and other parts or operations which are common to both the cast and welded designs, from our comparison.

The pattern cost, which is considerable, is given separately and is not entered as a part of the cost of the machine although we might fairly distribute this expense equally on the first 25 machines to be built. This is on the assumption that our sales would equal five machines per year.

In estimating labor costs, the unit of time is taken as one minute. The hourly wage is 80¢ and, allowing for 200% overhead, the hourly rate becomes \$2.40 or 4¢ per minute.

The price of iron castings weighing less than 100 lbs. or more than 100 lbs. where core work is involved is 6¢ per lb. For castings weighing more than 100 lbs., and without core work, the price is 5¢ per lb. For large steel castings, such as the gear rim used on this machine, the price is 10¢ per lb.

The estimated cost of the machine, built with cast iron and cast

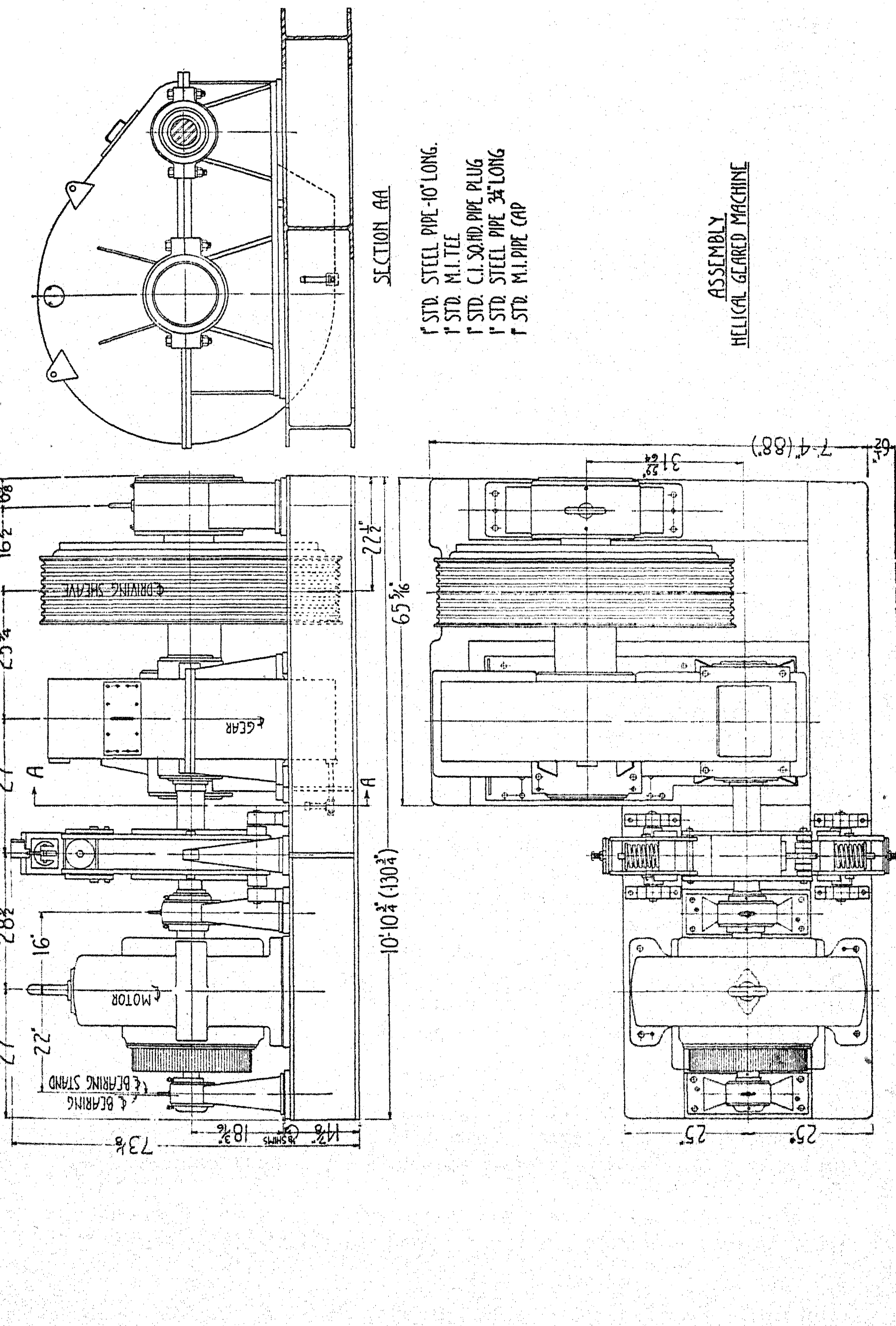

Fig. 2. Welded design of elevator machine.

steel parts, as shown on Fig. 1, would be too high to enable us to hope to compete successfully on sales of the maximum duties and still make a reasonable margin of profit.

During the past few years, the writer has, from time to time, designed many parts for various special machines where, on account of the high pattern cost, welded steel instead of cast construction was used. He, therefore, volunteered to design a machine which, with the exception of the motor and brake, would be made principally of welded steel. This would not only eliminate the pattern costs of the proposed machine but, because of the greater stiffness of steel over cast iron, would allow enough saving of weight so that the steel machine, when completed, would probably be more rigid and cost less than the cast machine even without considering the pattern expense.

Studies were begun and after the usual numerous changes of mind and ideas, which are never evident in the finished machine, the design as shown in Fig. 2 was prepared.

This machine, in regard to gear sizes, sheave and arrangement of parts, is practically identical with the cast machine previously described. No attempt was made to develop radical welded designs just to be different. Naturally, numerous "kinks" were tried out such as supportting the gear case bearings on parts of structural members welded into place instead of ribs and plates and fabricating the vertical members of the outboard stand from a large "H" beam with a "V" cut from the web and brought together against a central stiffener rib to gain sloping ends. Also, on the rotating gear and sheave unit, many layouts were made trying out various designs utilizing structural shapes, but they were all given up in favor of the construction as shown. Strangely enough, the design as a whole closely parallels that of the cast machine in important details.

In all essential parts, we have made the welded machine at least as stiff and usually stiffer than the equivalent cast construction. For example, the section through the bed plate shown on section A-A, Fig. 1, has a combined moment of inertia of approximately 2900 in ^{4}, while the section through the welded steel bed plate taken on the same plane has a moment of inertia of 1450 in ^{4}, neglecting the added effect of the finishing pads and the beam supporting the rear of the gear case. At the relative moduli of elasticity of steel and cast iron, the steel bed becomes stiffer than the one of cast iron with an accompanying large saving in weight.

The bed plate as shown in Fig. 3 serves as a base for the various parts of the machine. These parts are the motor, brake, gear case and the outboard bearing stand of the gear and sheave shaft.

This bed plate is not unusual in construction being built up of standard structural shapes.

At the joints, where the several "H" beams are connected together, the flanges and part of the web are cut away sufficiently to avoid unnecessary fitting. These connections of flange to flange are butt welds and of web to web are fillet welds, the fillets being the full length of the joint on both sides.

The finished pads, located on the top of the beams, are plates which, with the exception of two pads, are joined to the beds with intermittent

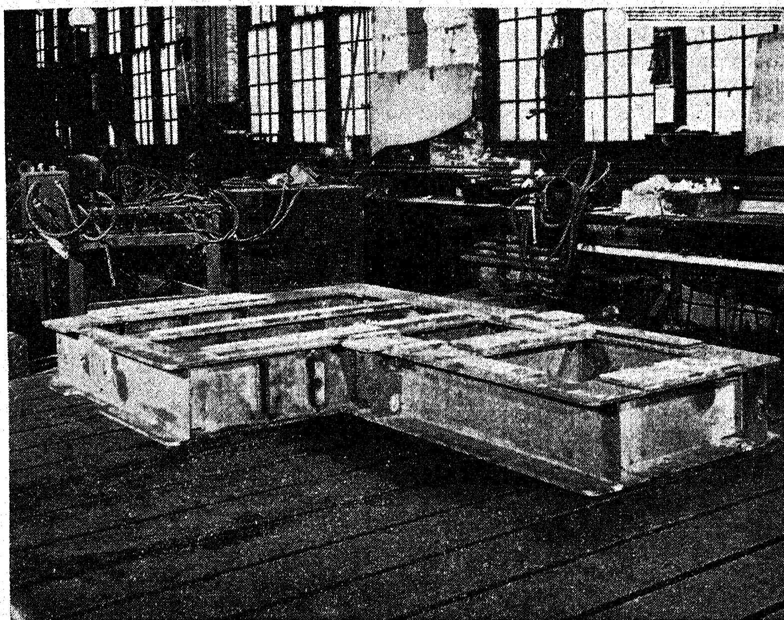

Fig. 3. Welded bed plate of elevator machine.

welds. These two pads, which carry the whole sheave shaft load of 100,000 lbs., have continuous 1/4″ fillet welds around the edges and, in addition, each of the pads is pierced with three 3″ diameter holes around the circumference of which are 3/8″ fillet welds. This is to overcome any flexibility of the pads, which might result from bulging of the plate and loss of contact between plates and beams. Stiffeners are added under the pads.

This bed plate was not stress relieved as we have found that in similar parts, which we have made, it has been unnecessary.

After welding, the top surfaces of the pads were planed and the necessary holes were drilled and tapped. As this bed plate, when installed, will rest upon unfinished supporting beams extending across the elevator hoistway, it was deemed unnecessary to finish the bottom of the bed plate. At any points found necessary, when lining up in the field, shims or liners will be used. This again would make machining of the bottom unnecessary.

The gear case is fabricated entirely of rolled steel. The first welded design contemplated the use of steel castings for the bearing housings and rolled steel for the remainder. However, due to the high cost of steel castings and the possibility of their being porous, and since no difficulty was expected or experienced in flame cutting the housings to shape from steel slabs, the rolled steel construction was adopted as the more satisfactory.

The maximum loads to be carried on the bearings are 39,000 lbs. vertical and 2,700 lbs. end thrust on the large gear and sheave shaft

bearing, and 10,600 lbs. vertical and 2,700 lbs. end thrust on each of the small pinion shaft bearings. The thrust loads, which are due to the tooth angles of the helical gears, are in one axial direction or the other depending on the loading and direction of rotation of the gear. When the thrust is toward the near side on the large bearing, the corresponding thrust on the smaller bearings is toward the far side and is taken by the bearing on that side. Reversal of direction of thrust on the large bearing results in a reversal on the smaller bearings.

The lower gear case has a vertical plate on the near side flame cut to the desired shape from ½″ steel plate and with bearing housings, flanges, ribs, foot shelf, etc., welded to its front surface.

On the far side of the gear case, the construction is practically similar to that of the front side, except that, instead of the large bearing, there is a reinforced opening comprising a stuffing box to permit the passage of the gear and sheave shaft. The thickness of the plate is ¼″ instead of ½″ as on the front side.

The cross members, forming the bottom of the gear case, consist of three parts of varying thicknesses. All of these pieces are of proper width to be flush with the outside surface of the side plates. One of these pieces is ¼″ thick, bent to suit the contour of the side plate, and extends from the lefthand side of the gear case to the ½″ thick horizontal piece. The piece comprising the right hand end of the case is ½″ thick.

All around the joints where the upper and lower gear cases fit together, there is a substantial flange arranged for a sufficient number of bolts to insure oil tightness. As a further assurance against oil leakage, bent up angle pieces, as shown at section K-K, are welded to the inside of the gear case to provide an oil barrier or trough at the joint. Occasional holes, drilled in the bottom of this trough, provide for drainage of accumulated oil.

A ⅜″ plate, bent to a channel form in a press brake, extends across the inside of the gear case just below the small bearings. This channel serves the several purposes of providing an auxiliary oil reservoir into which the pinion teeth dip, keeping the proper oil level around the roller bearings and adding great lateral stiffness against the changing of the distance between the roller bearings due to the applied external forces.

In assembling and welding the gear case, we were apprehensive lest we might run into distortion on account of the great differences in the thickness of the various parts to be welded together and also on account of the size of some of the welds. Fortunately, the design is such that most of the complications obtain on the front and back plates. The cross plates are simple straight and curved sheets serving only as the bottom of the oil-tight gear housing. We, therefore, placed the front plates, already flame cut to the desired shape, flat upon a platen and assembled the bearings, flanges, foot piece or shelf, and ribs in their proper positions on the plate, tack welding them into place. This sub-assembly is shown clearly in Fig. 4.

Before beginning the welding, the tack welded front sub-assembly was very securely clamped to the rigid platen and then the parts were welded. In addition to the parts shown in Fig. 4, a ½″ plate was cut to

fit the bottom contour of the large bearing and welded into place. After welding, the piece was allowed to remain clamped until cool when it was removed and carefully inspected for warpage. To our surprise and gratification, no discernible warpage or distortion was evident.

The back plate of the gear case was then assembled and welded in the same manner and with as little difficulty.

To assemble the front and back plates with the cross or bottom plates presented no great problem and was easily accomplished. The parts

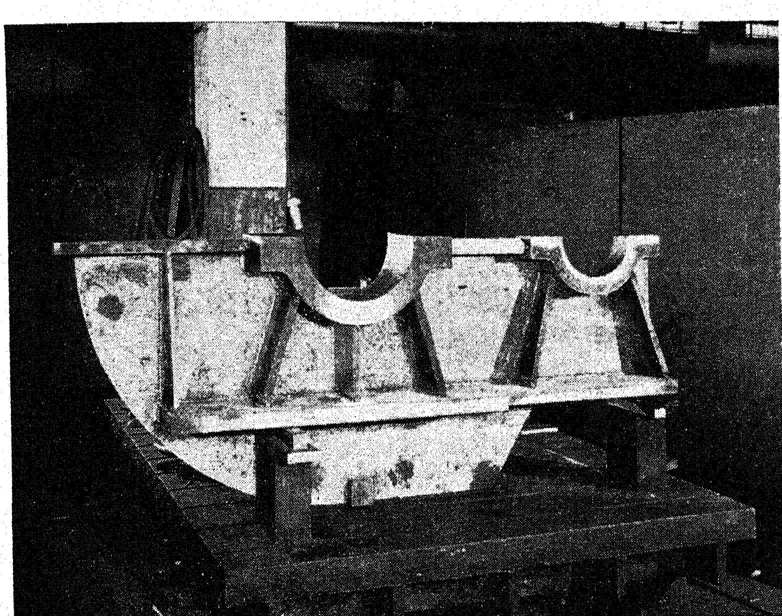

Fig. 4. Sub-assembly of gear case.

were merely tack welded in their proper relationship with each other by an expert layout man, the usual temporary spacers tack welded in position and the weld metal applied.

It will be noted that the joint is made with the cross plates flush with the outside surfaces of the front and back plates. Our first impulse was to make the joint with an overlap on the outside so as to provide for an outside fillet weld. This would be desirable from the standpoint of accessible welding and, as intermittent fillet welds could be placed on the inside corners as well, there could be no doubt as to the strength. But the question of appearance was one which could not be neglected in this design and the projecting ledge which would result from an outside overlap would not be as smooth looking as a regular, sharp corner. Therefore, the design was adopted with gratifying results on the finished gear case, as will be seen in Fig. 5.

The cross plates were cut to width with smooth straight edges and as they were laid flush with the outside of the side plates, no projection

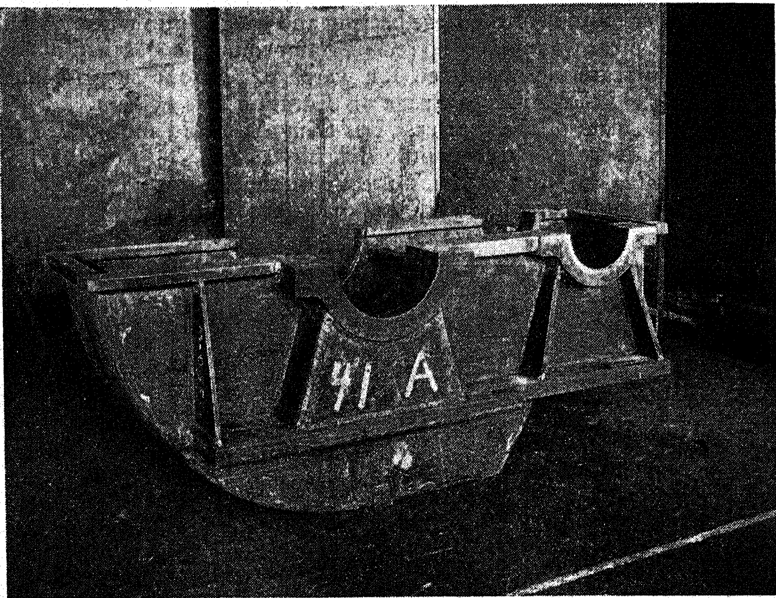

Fig. 5. Arc welded gear case, complete.

of any kind appeared at the corners. In addition to the continuous inside fillet weld, a filler bead was run along the crack, left between the sides plates and the cross plates by the slight irregularities of the flame cutting, and the joint was then ground smooth with a hand grinder so that no joint of any kind is visible.

Finally, the angles and the cross channel, were welded into place. This, with the addition of the flanges at the end of the gear case, completed the welding of this unit, which was then stress relieved.

As mentioned earlier, no effort has been spared to make this gear case as rigid as is practically possible. For that reason, the righthand end cross plate and the horizontal bottom cross plate are 1/2" thick. Assembled as they are, they give the effect of tying the front and back plates together with an 18" x 16" x 1/2" angle which, with the addition of the cross channel under the adjacent bearings, provides stiffness to prevent "wringing" of the gear case under load.

The flange between the two bearings on the front plate is 3" wide x 1 1/2" thick butt welded on each end with 100% welds. It, in combination with the similar flange on the upper gear case, comprises a strut 3" x 3" in section between the two bearings. This is important and is necessary to prevent gear noises caused by any possible variation in dimensions between the center of the gear and pinion which might result from deflection of the supporting beams, or the bed plates, or both, due to change in load on sheave.

The upper gear case, as shown in Fig. 6, is made to fit on the lower gear case, as just described, and the similarity of construction is such that a detailed description would seem repetitive. It should be noted,

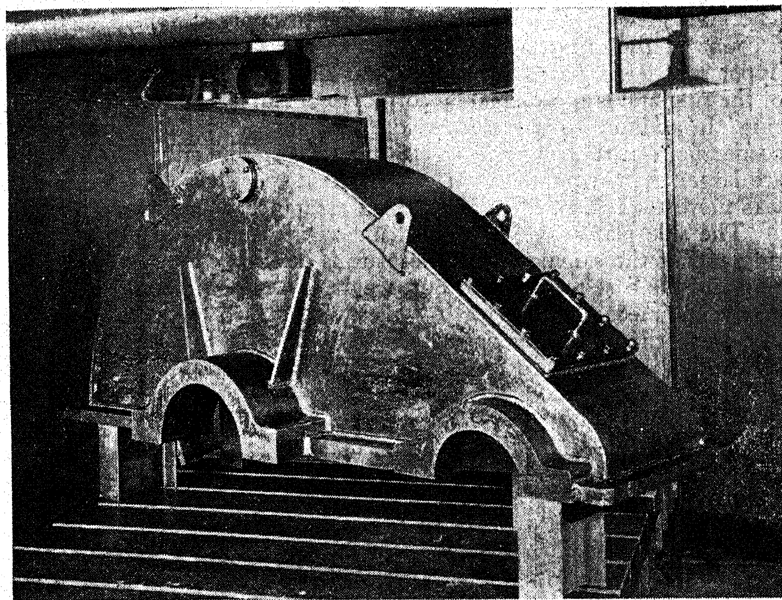

Fig. 6. Upper gear case of elevator machine.

however, that the front, back and cross plates are all 1/4" thick. The flanges remain of the same thickness as on the lower case to furnish an adequate oil-tight joint and provide the required strength between the front bearings as mentioned in the description of the lower case.

An observation hole located above the pinion shaft bearings is for inspection of the gear and pinion teeth.

After welding and stress relieving, this gear case as well as the lower gear case were planed on the horizontal finished surfaces—namely, the joints between the upper and lower case, and the bottom of the supporting shelves on the lower case. The upper and lower cases were then bolted together and the holes for the roller bearings, as well as the opening for the gear and sheave shaft, were bored. Next, the various holes were drilled and tapped and all other work was completed.

The sheave shaft stand, or outboard bearing stand, is designed to contain a double-row tapered roller bearing which will be subjected to a maximum radial load of 70,000 lbs. The direction of the applied load may vary from vertically downward to 45 degrees from the vertical. All of the parts comprising this stand are of steel SAE-1020.

The construction is very simple and direct with straight lines used wherever possible. The housing is made from a ring bent to cylindrical form and welded. The base is 40" long x 11" wide flame cut from a 1 1/2" steel slab. The middle strut connecting the base with the ring is a piece 9" wide x 5 3/4" long x 1" thick double beveled at each end. The 9" wide x 13 1/4" long x 1" thick pieces, which form the ends of the rectangular section, are beveled at 40 degrees on the lower end.

The 40-degree bevel affords ample space to apply the weld metal on account of the increased opening due to the slope of the parts. The upper end, left square, makes a natural angle with the outside surface of the ring and is approximately correct to obtain a 100% weld with the ring. In addition to the main weld, there are ½″ welds on the inside corner both at the ring and at the base plate. The sizes of the welds are larger than required but it was felt that the slight increase in cost was more than justified by the added assurance of safety.

The side plates are ½″ thick flame cut to suit the contour of the ring and of the sloping end. The plate is beveled where joined to the ring and the base to allow for butt welds. The sloping ends are lapped on the end pieces to allow for ½″ fillet welds. Two 1″ holes are drilled in each of the ½″ plates opposite the middle strut to provide for plug welds. These welds are made flush with the surface of the plate for the sake of appearance.

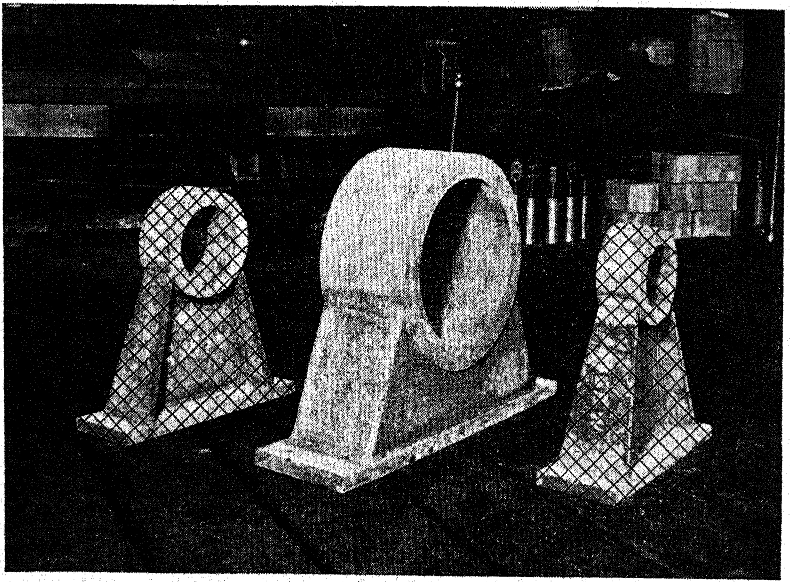

Fig. 7. Sheave-shaft stand arc welded.

Welded, the stand resulted in a tremendously strong and rigid support for the large roller bearing and deflection in this member under the load of 70,000 lbs. will be practically nil.

Reference to Fig. 7 will show that the appearance is pleasing and in harmony with the bearing located on the front of the gear case.

The sheave shaft, with the gear and sheave centers or spiders welded to it, was the last of numerous studies made on this unit. Even after welded design was adopted for the bed plates, gear case and outboard stands, we still continued to show the same construction on this unit as on the one described for the machine where the above parts were

of cast iron. The reason for this persistence is that it was difficult to dissociate the gear and sheave centers from an integral connecting neck or hub forced on a shaft. Even after deciding that welded construction for this piece would at least save the cost of the quite expensive patterns which would be required, we continued to show a common hub of steel forced on a shaft. Finally, however, the fact seeped into our minds that boring a hole in a steel hub and then filling it up with a shaft was not consistent with the desired economy.

It was, therefore, decided that both the spiders were to be welded directly to a shaft which would be of such diameter that the bending stresses under load would be so low that the deflection would be slight. This would result in the alignment of the gear and pinion being maintained under varying conditions of loading.

Welding the rings or discs, cut from plates which form the side of the spiders, directly to the shaft with the possibility of undercut welds, aroused some apprehension. Even with the low calculated stresses used, it was feared that stress concentrations which would obtain at circumferential notches in the shaft might cause fatigue cracks to start. Once started, these cracks would progress due to the continued stress reversals in the rotating member and would result in eventual fracture of the shaft.

To eliminate this serious possibility, at each end plate of the spider the shaft is enlarged by annular rings. These rings serve the double purpose not only of eliminating the effect of undercutting during welding but also of preventing the rapid heat transfer that might result from laying a weld directly on the shaft itself with possibility of shrinkage cracks due to abrupt change in thickness of the materials being welded.

The actual assembling and welding of the various pieces in their positions were not difficult, but the job was done by an expert layout man and welder and the result justified the care and skill used.

As a matter of curiosity, the partly completed unit was placed on lathe centers and rotated to determine the amount of inaccuracy that might have crept in. It was found that the circumferential or radial "runout" was $\frac{1}{64}''$ maximum while the greatest lateral variation from maximum to minimum at the largest diameter was .020″. This accuracy was far greater than we had hoped to get and was very gratifying. Fig. 8 shows the unit nearing completion.

The welding completed, the unit was placed in the annealing furnace and stress relieved. In this case, the usual procedure of holding at 1150°F. for one hour for each inch of the thickest part was not followed as the $12\frac{1}{2}''$ diameter shaft was in no need for stress relieving except at those portions where it was joined to the end plates and webs. Therefore, it was arbitrarily specified that this unit should be held for six hours at 1150°F. and then allowed to cool slowly in the furnace to 200°F.

A careful inspection revealed no cracked welds and no distortion. It was necessary to be very particular in the welding of this unit, especially at the points where the plates or discs are joined to the shaft. The load on the sheave will be 100,000 lbs. and, as the shaft revolves, any stresses in the welds, due to the applied load, will be subject to reversal

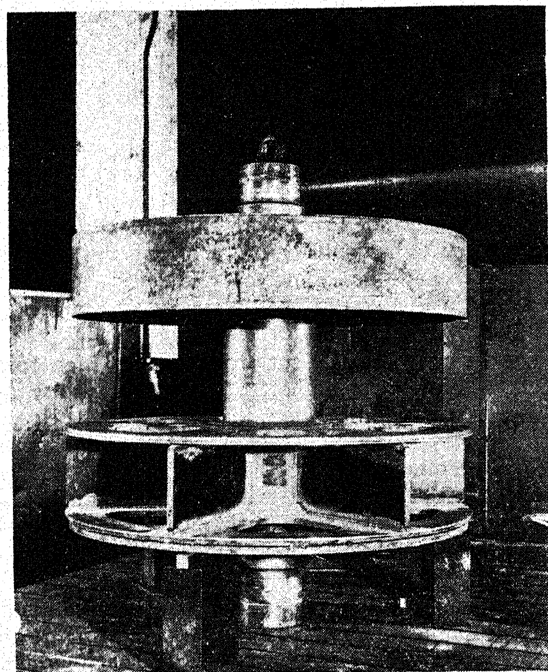

Fig. 8. Sheave-shaft unit.

which is apt to spell fatigue failure if the weld is not properly made.

After stress relieving, the finishing was completed.

The helical gear consists of a ring of steel S.A.E.-1045, and a continuous internal flange flame cut to size from steel S.A.E.-1020. The ring and flange are welded together. The teeth are single helical and of such pitch and helix angle, that there are exactly two axial pitches in the face width thus insuring that the same number of teeth will always be in contact; the contact lengths will always be the same; and vibration, because of variations of length of contacts, will be eliminated.

The ring of steel S.A.E.-1045 was purchased from a manufacturer of locomotive driving wheel rims who was equipped to make ring forgings. Before making the next machine, we will try bending a ring to shape on bending rolls with the joints cut on the bias across the teeth so that the welded portion on each tooth will be a small part of the total length of tooth and we will use an electrode which will suit the material of the ring. In the present instance, however, where only one machine is involved, it was thought preferable to obtain a continuous ring and avoid the welded joint.

After welding, the blank was stress relieved and machined to size. The teeth were cut and then the gear was forced on the gear spider and fastened with 12—1″ bolts through the flange.

The assembly of the gear and sheave shaft with the gear and sheave in place is shown in Fig. 9

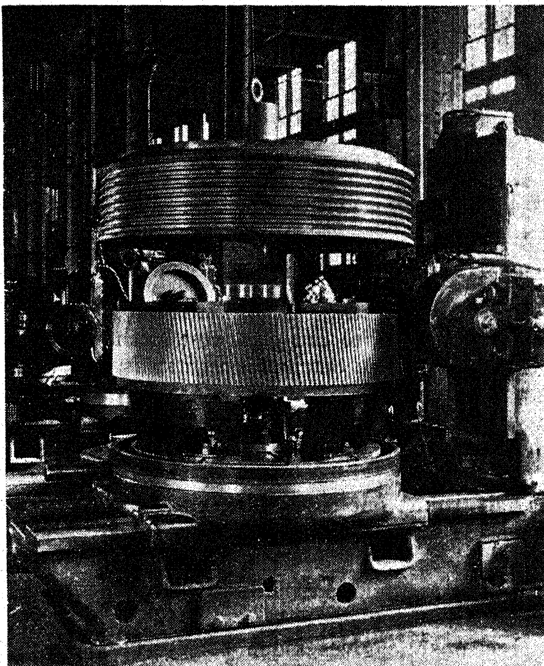

Fig. 9. Assembly of gear and sheave-shaft with gear and sheave in place.

The costs and weights of the cast and welded constructions show that there is a decided advantage in favor of the welded machine. The cost of the cast construction is approximately 55% higher than that of the welded and the weights are in about the same proportion. If the pattern costs are also taken into consideration, the difference will be greatly increased and if these pattern costs are amortized over a reasonable number of machines, say 25, the difference becomes so great that cast construction should not even be considered.

COMPARATIVE COSTS

	Cast Construction		Welded Construction
Item	Cost	Pat'n. Cost	Cost
Bed plate	$ 569.00	$1400.00	$204.77
Upper and lower gear case (less covers)	243.60	950.00	194.13
Gear case covers	16.44	110.00	29.43
Sheave shaft bearing stand (with covers)	73.66	390.00	62.10
Sheave shaft assembly (less gear and sheave)	412.30	475.00	337.01
Finished helical gear blank	194.80	100.00	134.25
Total cost of comparable parts	$1509.80	$3425.00	$961.69

Saving per machine = $1509.80—$961.69 = $548.11
Cost of patterns = $3425.00
If amortized over 25 machines,
Pattern cost per machine = 137.00

Saving, welded over cast = $685.11

Percentage cost of cast over welded construction including patterns based on total of 25 machines=71½%

COMPARATIVE WEIGHTS	Cast Construction Wt. Lbs.	Welded Construction Wt. Lbs.
Bed plate	9460	3980
Upper and lower gear case (less covers)	3500	2185
Gear case covers	134	160
Sheave shaft bearing stand (with covers)	1091	950
Sheave shaft assembly (less gear and sheave)	5905	4675
Finished helical gear blank	1616	1350
Total weight of comparable parts (rough)	21706	13300

Saving per machine = 21706 lbs.—13300 lbs. = 8406 lbs.

The greater weight of the cast construction also may not be neglected as it indirectly adds to the gross cost of the elevator installation in the following way. The machine and its suspended loads must be supported on beams which span the hoistway. The heavier machine requires heavier beams which add to the cost. The building structure, by which these beams are supported, must also be heavier at still more added cost, etc., etc.

Without half trying, one is forced to the inevitable conclusion that the welded machine is the only one that you dare build.

"But," you may say, "what of the appearance? Will not cast construction lend itself to smoother outlines, rounded corners, large fillets and absence of visible joints?"

Perhaps, but no one gives much consideration to these features now-a-days. The engineering profession and the manufacturers are so rapidly becoming "welding minded" that a well engineered and executed welded design has more of an appeal than the round corners, tapered flanges and large fillets of the conventional casting. Where are the beautiful(?) curved legs that we saw on the lathes and other machine tools of 25 or 30 years ago?

It is the writer's opinion that a welded design should not attempt to simulate a casting at all. He also believes that the first consideration in welded machine parts should be that all the metal is placed to the best advantage according to engineering principles. At the same time he does not believe that a design should be approached with a slovenly attitude of mind such as "It looks good enough. It's only welded."

As an example, if you will refer to Figs. 5 and 6, it will be noted that the outside corners of the gear case are square, with no visible joints. This was mentioned earlier in this paper. The joint, as first contemplated, was made with a re-entrant angle at the corners to facilitate the welding which could then be made on the outside. At practically the same cost, the corners were made with the plates flush with each other and with greatly improved appearance and no sacrifice in the construction from an engineering standpoint.

And while on the subject of appearance, it is our opinion that no attempt should be made to conceal welds. A well executed weld is beautiful enough in itself and, on a small scale, it is as great a pity to disguise it with filler and paint as it would be to carry out the original intention and conceal with masonry the beautiful outlines of the steel towers of the George Washington Bridge.

We began the design of the welded machine as described with the belief that it would save the cost of expensive patterns and the hope that it might cost even less than the cast machine on the basis of five machines per year. As a result of our study and actual experience, we know that on the basis of any number of machines per year, five or five thousand, the welded design would still be preferable from any viewpoint—weight, cost, strength or appearance.

We have several other large machines which might also show to good advantage if made of welded rolled steel. We shall see.

Chapter X—The Use of Electric Arc Welding for Building Hoisting and Conveying Equipment

By R. De Buire,
Engineer, Paindavoine Works, Nord, France.

Harbor cranes, of all handling and conveying apparatus, have to be the strongest on account of their uninterrupted operation; also, on account of the speed of operation required. Due to the necessity of detaining ships ashore during the shortest possible period, engineers have had to design equipment which, both for starting and stopping, responds at once to the reflex movements of the operators. The accelerating and stopping periods of the different motions of a crane have, thus, been considerably reduced.

It might have seemed risky and even unwise to undertake the building of four entirely welded harbor cranes, but the practical results actually obtained have exceeded the most optimistic expectations.

Therefore, before describing the main points connected with arc welding, it has been thought advisable to indicate the main features of the equipment constructed.

The cranes, the outline of which greets the passengers of incoming steamers, are of various shapes and sizes according to the countries and builders.

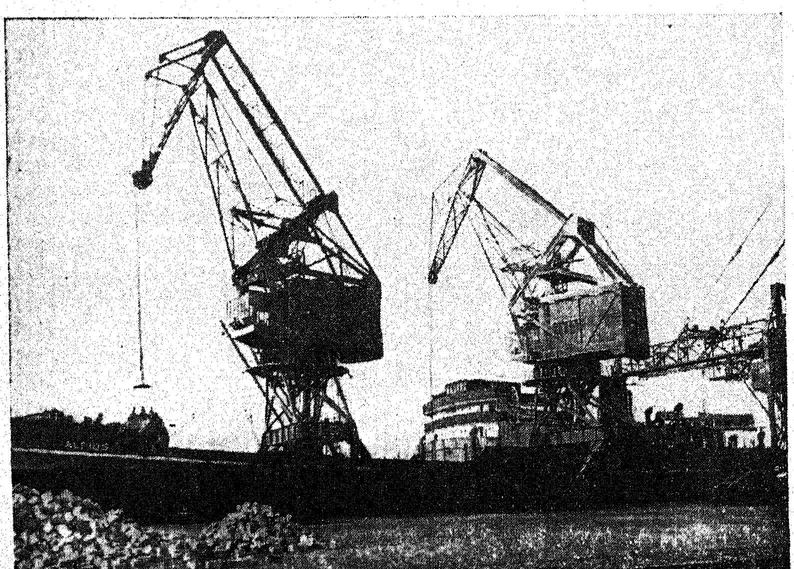

Fig. 1. Harbor cranes with luffing jib and horizontal conveyance.

Those which will be described here are of a fairly recent type, with luffing jib and horizontal conveyance of the load by means of the linked jib.

The general shape of these cranes is shown in Fig. 1.

Their main features are the following:

Lifting power—max. radius	10 tons
Dynamic test load—max. radius	12.5 tons
Static test load	25 tons
Maximum radius of crane	22.950 m.
Minimum radius of crane	8.950 m.
Horizontal travel of luffing jib	14.000 m.
Travel of portal	8.600 m.
Opening of portal	5.200 m.
Height of head sheave above dock	20.000 m.
Total lift of load	30.000 m.

OPERATING SPEEDS

Lifting speed	72 m. per minute
Descending speed	90 m. per minute
Slowing speed	2 r.p.m.
Lifting of jib, full 14 m. travel	16 seconds
or at the rate of	54 m. per minute
Travelling speed of portal	12 m. per minute

MOTOR POWER

Lifting	200 H.P.	
incl. 1 motor for lifting or closing	100 H.P.	1000 r.p.m.
1 motor for holding or opening	100 H.P.	1000 r.p.m.
Slowing—one motor	30 H.P.	750 r.p.m.
Lifting of jib—one motor	30 H.P.	750 r.p.m.
Travelling—one motor	25 H.P.	1000 r.p.m.

Electric power: 380 volt, 50 cycle three-phase current.

The operation is fully automatic with switch control.

The calculations have been made on the basis of wind action at the rate of 250 Kilos per sq. meter.

The total weight of one unit in working condition is 160 tons.

Obviously, the framework and mechanical parts form a considerable portion of this weight of 160 tons and, in order to make this paper quite clear, it is necessary to examine them in turn, but without going too much into the technical details of the apparatus to the detriment of the main object: the use of welding.

Description of Framework.—The structure of a harbor crane includes a portal, a revolving upper structure and a jib.

The portal, as its name implies, consists of vertical upright members or columns and of an horizontal girder system which must be very strong as it has to support the total weight of the machinery and framework and stand dynamic effects of all kinds.

It should, therefore, be made of very stout structural sections and, in the case in point, of the plate-girder type.

The use of rolled beams was impossible due to the necessity of having uprights of equal strength both for obtaining large corner connections and to answer to the prescribed space requirements.

The main legs and girders are of I-section, but are formed by special ribbed flat strips, specially rolled in order to avoid costly bevel-machining operations.

The plate thickness being about 12 to 20 mm, welding without bevelling could not be allowed.

This ribbed section offers the following advantages: it eliminates the difficulties met with in making corner or fillet welds. It allows the seam to penetrate in depth and not laterally as in the case of corner fillets. It makes it possible to weld heavy sections right through without necessitating a preliminary bevelling of the plate.

In addition, I-sections may be obtained with any distance between flanges and any required web and flange thickness, thus doing away with the piling up of plates for forming chord members with a moment of inertia in proportion with bending moments.

Ribbed flanges and bevelled webs would be ideal if the desired shape could be obtained by rolling, as it would reduce the amount of deposited metal while allowing the arc to strike normally in the plane of the joint.

But this is a matter for future consideration in connection with rolling mill design.

It will be noticed that this method of fabricating I-sections of any depth results in a neat appearance of girders and uprights of variable width.

The members connecting the two faces of the portal consist of two channels braced by means of plates welded at the ends of the channel flanges. These members are thus very plain without excessive bracing.

All shop-built framework units have been assembled without the use of bolts. On the other hand, such units as were mounted on the site were provided with a few bolt holes in order to facilitate setting and ensure the correct connection of members during the welding operation.

After the latter has been completed, the bolts are of no further use and they were only left for the sake of economy.

It will also be noted that gussets no longer consist of plates covering all the members joined, but of simple triangular pieces welded between the edges of the bars.

Only on gussets, the saving in weight obtained on a crane amounts to 4.000 Kilos, that is, nearly 2.5%.

Due to the remarkable ease of fabricating members of high inertia, the number of secondary bracing members may be reduced while preserving the same buckling strength for an equal weight, so that the justified objection against steel structures, that they show such a multitude of members—a maze of bars to the layman—tends to disappear, as Fig. 2 shows quite plainly.

This remark applies to an even greater degree to the revolving upper structure and jib described hereafter.

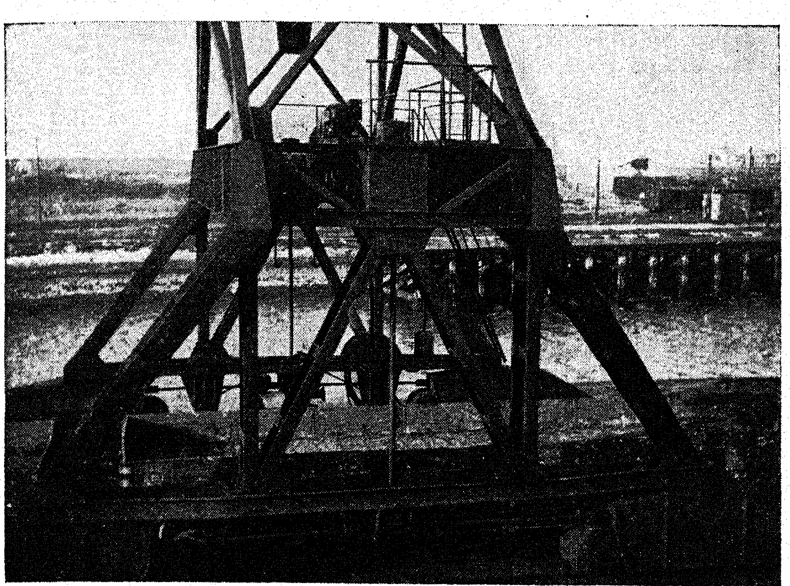

Fig. 2. Arc welding reduces number of members in a structure.

The four portal supports rest on four-wheel boggies of particularly neat and economical design.

The bolt heads shown serve for fixing the travelling mechanism.

The welded plate boggie construction offers no special difficulty and the designer is in no way hampered in selecting the shape which he thinks most desirable. It is an easy matter for him to meet all requirements as regards safety, overall dimensions, maintenance, dismantling, or even wind resistance.

In addition to the above facilities, the use of welded plate boggies, as compared to that of cast steel units, results in a saving of 20 to 30% in weight, and 10 to 15% in cost.

The portal is surmounted by a framework braced in all directions for raising the crane cabin above the level of ship bridges.

The base of this framework is plainly visible in Fig. 2.

It should be noted that this framework is particularly exposed to wind action on account of its high level above ground.

A welded section had to be found, combining non-buckling qualities with a minimum of wind surface.

To this end, tubular sections have been developed, which are formed with standard structural steel sections.

In the case in point, channels were longitudinally welded together.

In order to reduce fatigue, there remains the possibility of reinforcing the webs without changing the area exposed to wind action.

Before examining the manifold advantages offered by tubular sections, it appears useful to figure out an example showing the technical advantages as regards the strength of the structure and the reduction in cost attained by the builder thanks to careful designing work.

Let us take the following example:

A member of the framework over the portal is submitted to a load of .... 15.000 Kilos

Its buckling length is............................. 30. m.
Previously, it would have consisted in a rolled 140 x 140 I-section. It now consists of 2 channels forming a [ ] tubular section.

With the welded tubular section, two solutions may be adopted: either with same wind surface and increased strength, or with same strength and smaller wind surface.

What will be the reaction on cost price?

1) 140 x 140 mm rolled I-section
   Sectional area: 4.580 mm^2 I minimum 4.584.000 MM^4
   Weight per lineal meter 36 Kilos.

$$\text{Buckling fatigue} = \frac{15000}{4580}\left[I + 0.0001\ \frac{(3000^2 \times 4580)}{4.584.000}\right] = 6.25\ mm^2$$

2) Welded section of same height, or 2 140 x 60 x 7 mm [
   Sectional area: 4080 mm^2 I minimum 9.000.000 MM^4
   Weight per lineal meter 32 Kilos.

$$\text{Buckling fatigue} = \frac{15000}{4080}\left[I + 0.0001\ \frac{(3000^2 \times 4080)}{}\right] = 5.15\ mm^2$$

3) Welded [ ] section of same strength as 140 x 140 I-section, or two 120 x 55 x 7 mm channels
   Sectional area: 3400 mm^2 I minimum 7.280.000 mm^4
   Weight per lineal meter 26.7 Kilos.

$$\text{Buckling fatigue} = \frac{15000}{3400}\left[I + 0.0001\ \frac{(3000^2 \times 3400)}{7.280.000}\right] = 6.25\ Kmm^2$$

Assuming an average price of 1.30 Fr. per Kilo of structural steel, the second solution, as compared to the first, shows—

Same wind surface
Reduction in weight—11%
Increase in strength—17.5%
Price of I-section per meter—1.30 x 36 = 47 francs.
Price of [ ] 140 section per meter—(1.30 x 32) + 6 = 47.5 Fr.

6 Francs represent the value of six 3 mm electrodes, labor and power for welding the two channels along one meter: Prices equal.

The third solution, in relation to the first, shows:
Reduction of wind surface—14%
Reduction in weight—26%
Same strength

Price of I-section—1.30 x 36 = 47 francs.

Price of 120 [ ] section (1.30 x 26.7) + 6 = 40.5 francs, which means 14% reduction in cost of material.

In actual practice, the saving in sectional steel of different sizes has amounted to 10%.

Welded tubular sections are, therefore, economical, very rigid, with a smaller wind surface.

In addition, they are perfectly corrosion-resisting; the closed and

watertight tubes have their inner surfaces protected from the weather, all external faces are easily maintained by painting over flat surfaces, there are no gaps as in the case of][or]⌊ sections, which cannot be reached with the brush.

The saving in maintenance work is appreciable, as there are only four faces to be painted instead of six in all other cases, which means 33.5% less paint.

The advantages of welding are, in this case, both undeniable and important, as it is practically impossible, with the usual riveted construction, to obtain tubular sections ranging between 30 x 30 mm squares up to 300 x 200 mm rectangles. Any sizes over the latter may also be obtained by using four plates and four welds at the corners.

All exposed foot-bridges are made of expanded sheet with 5 x 8 mm strips, the diamond points being welded on angles which are sufficient to withstand bending between supports.

The purchase price of expanded sheet being rather high, there is no immediate profit in adopting this construction, but the floor thus obtained is stiffer than with plain or ribbed sheet. There is no accumulation of snow or rain water and, in the case of inclined foot-bridges as on the jib, wind action does not have to be considered and the weight of foot bridges is reduced by no less than 30%.

The railings consist of standard round tubing for uprights and railings (handrails), the lower bars being round rods of smaller diameter.

On the top of the portal is installed the so-called slewing frame.

Usually this frame consists of straight beams forming a square on which is mounted a circular iron or steel casting called the slewing crown. The periphery forms a large gear and spokes hold the vertical pivot of the revolving crane in a central position.

An independent circular rail for slewing wheels is sometimes added, which complicates the construction.

The construction of such a slewing frame is always of an empirical character. The designer assumes that the square frame will absorb vertical loads, that the crown will withstand tangential forces and the pivot horizontal stresses.

In reality, such is not always the case. The crown and the rail cancel part of the horizontal forces due to the friction of the wheels. As to the vertical forces, they are transmitted somehow, due to the static indetermination of various parts or different shapes laid over each other.

Arc welding has made it possible to obtain a construction which is both more rational and harmonious.

A circular beam resting on 8 supports, (4 supports might have been adopted with advantage), is provided for absorbing vertical, tangential and horizontal friction forces; the balance of horizontal forces due to wind and slewing torque being transferred to the pivot.

The calculation is that of a ring resting on 4 or 8 supports, as the case may be.

The slewing crown is a plate girder which receives the rail in line with the web and, on the outside and upper periphery, round spindles forming a gear of suitable pitch.

The construction job is easy, thanks to the absorbing power shown by rings with respect to internal and contraction stresses.

These crowns were built up with flat plates without ribs, due to the flanges being set out of center on the web, but the web was bevelled as well as the lower plate of the spindles. The seams were made with one bead at the bottom of the Vee, using 4 mm electrodes and one final 8 mm bead on the flanges, the stiffeners being welded in one run with 4 mm electrodes.

In addition to the advantages pointed out above, it should also be mentioned that the design has made it possible to install a circular foot bridge made of expanded sheet, which gives access to the operator's cab for any position of the crane and even during the slewing operation by means of a ladder fastened to the revolving unit, as shown in Fig. 1.

The maintenance of the pinion, slewing spindles and wheels is made easy thanks to the convenient means of access without the real dangers run by the staff with the older types of construction.

Revolving Upper Structure.—This includes a revolving frame and horizontal platform with which the framework carrying the jib links is connected.

The revolving frame platform is designed for receiving the cabin containing the machinery, hoist, electrical equipment and, in front, the operator's cab.

The cabin for the machinery is made of wood and shows no special features.

The operator's cab, glazed on all sides and on top, is made of small structural steel sections assembled by welding. It is therefore very well lighted and offers a perfect view in every direction. The adhesion of putty around the panes being more or less imperfect, cracks subsist between steel and putty, where rain water is apt to gather. The corrosion is very rapid, especially with steel of small section and permanent protection cannot be ensured by means of paint.

The cab window frames have, therefore, been metallized after welding and carefully removing the slag so that the adhesion of the sprayed metal is perfect.

The frame which revolves around the above-mentioned pivot rests on a set of small slewing wheels and, as a whole, does not appreciably differ from the usual construction.

However, the loads transmitted by the upper structure, hoist, slewing gear, fixed counterweight projecting downwards at the back of the frame, is such that standard structural steel sections are of inadequate strength and dimensions, the ideal height for the frame being 0.600 m.

The girders have therefore been fabricated, use being made, for the I beams, of ribbed strips as for the portal girders, and for the [beams, by assembling two angles and a web of suitable thickness.

The selection of suitable sections for the calculated stresses is made quite easy, which could not be obtained by using rolled beams.

The secondary bracing members show no particular features.

Composite sections have also been adopted for the upper structure, for the following reasons:

The cabin is quite independent from the framework and no member is made to pass through the roof in order to prevent rain water from dripping in.

In order to keep within the prescribed overall width, the members running along the cabin wall had to be as thin as possible. The use of tubular sections was therefore undesirable.

The reduction in thickness, of course, called for a corresponding increase in width, which seems to be in contradiction with the attempt to reduce wind surface. This is not really the case, for the members are adjacent to the cabin and the width is of no importance, the cabin forming a screen.

As regards the members above the cabin, the number of bars has been reduced as far as possible by using very open lattice work.

Thus, only one upper structural member is wide: it is the one which receives the jib pivots. This is of advantage as it facilitates boring and, in addition, there is no cumulative effect of wind surface, as the various luffing organs are in alignment.

The link pins are housed in bored holes, reinforced by plates welded on either face of the web.

The front and rear faces consist of rigidly connected portals spanning over the cabin or cab.

The front face, in particular, calls for a very large section as the uprights of same are connected with the adjacent members of the side faces, so that the cross section is represented by a very large angle.

Crane Jib.—The jib is the unit which, although it should be designed with care, has most benefited by the use of tubular sections and very open bracing allowed by electric welding.

The outline is neat, without any excess of bracing bars serving questionable purposes, the members look slender as compared to the three cranes seen further away, which are only of 3-ton capacity, but of riveted construction, where the entangled lattice work is conspicuous and characteristic. The five cranes in the background are also of riveted construction.

The difference in appearance in relation to the capacity, speaks strongly in favor of welded construction.

The analysis of the jib in this connection is interesting.

The linked jib of a crane of this type includes: an upper jib of triangular shape at the top; a back tie: it is the straight plate girder connecting the back of the upper jib with the apex of the upper structure; a pusher: it is the braced girder connecting the central axis of the upper jib with the lower axis of the upper structure below the glazed car; the counterweight lever and connecting rods balancing the jib.

As the upper jib reaches out to a radius of 23 m. and up to a height between 22 and 30 m. it is obvious that its own weight and wind surface exert an outweighing influence which affects the whole structure of the crane and its bearings.

All the facilities offered by welding have therefore been utilized to the greatest possible extent for this part of the job.

For the longitudinal beams, use has been made of tubular sections of minimum surface and maximum inertia.

The horizontal members are arranged on the plane of the tubular chords and butt-welded. They are, therefore, sheltered.

The bracing is very open. The footbridge giving access to the jib head sheave is of expanded sheet, hence no wind effect with short radius, no snow overload with long radius.

These tubular sections, consisting of angles, offer the same advantages as those built up with channels as described above.

The tubular member connections were obtained in two different ways, according to whether one-piece or composite gussets were used.

One-piece gussets were used for connections under statically determined conditions, or when their fabrication was more economical. In this case, the ends of members were mortised, the gusset acting as a tenon.

Composite gussets were used where the butt-welded joint between members was not thought strong enough and the gusset was meant to reduce the buckling length of the members.

Both methods were nevertheless subject to considerations connected with the economy of construction when making the drawings, as it has been found that in every case butt welds were sufficiently strong to stand compression stresses and often to absorb tension stresses.

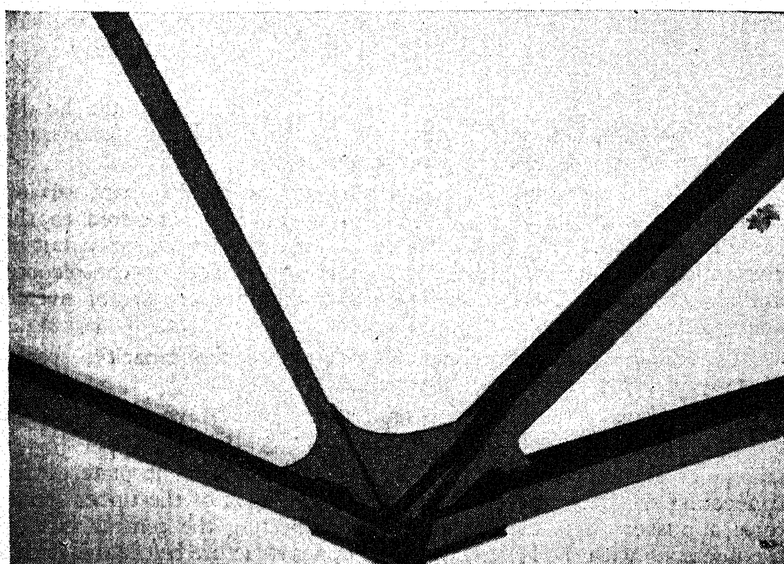

Fig. 3. Arc welded connection in crane frame.

There is no need to dwell on the favorable results obtained with this type of construction and Fig. 3 is very suggestive as regards strength, ease of execution and appearance.

A kind of joint where a comparison between riveted and welded construction shows distinctly in favor of the latter method, is the fastening of bearings on a piece of framework.

The chords are fitted with blocks of suitable thickness to withstand the stresses, this being obtained without disturbing the continuity of the structure, the sectional members being welded on the blocks, a great stiffness in every direction is thus obtained.

The front and rear upper jib ends carry supporting frames for the rope deflector sheaves.

The bearings are arranged in an outboard position on the framework by means of a suitable girder system connected with the supports without superposition of beams.

The back tie consists of two plate girders submitted to tension in the balanced condition of the system and to bending under its own weight.

The bending distortion ordinates determine the depth of the girder, which is given a variable section of uniform bending strength.

The girder depth varies between 300 mm at the supports and 660 at the center.

In spite of this variable section, the girder has a [section and consists of a 6 mm thick web and two 70 x 70 x 7 mm angles.

The bracings are sheltered by the tie so as not to expose an extra surface to wind action.

The pusher is identical in construction to the upper jib. The main open braced girders consist of tubular members and the bracings are also arranged on the same plane as the chord members.

Apart from its dimensions, which are larger, the pusher does not show any feature which has not been mentioned for the upper jib and there is no need to refer to it again.

Counterweight Lever and Connecting Rod.—These units also consist of tubular members. The lever has the shape of a triangle, linked at one angle. At one of its free ends is fixed the 13,500 Kilo counterweight, at the other are fixed the connecting rods acting on the pusher.

These units can only be braced on one plane due to the variable position of the framework and luffing mechanism during the operation.

In order to replace the bracing, the arc welding method has made it possible to build reinforced beams with long connections.

Description of Machinery.—The use of electric arc welding for building mechanical parts is easier than for structural work.

The effects of contraction affect parts of smaller dimensions, the seams are short in proportion to the amount of base material and in special cases cooling may be controlled or parts may be preheated and annealing may be performed in ovens of suitable size.

It may, therefore, be said that electric arc welding can, in every practical case, be used for constructing mechanical parts.

The saving in material is undeniable and sometimes reaches 50% on the weight of castings.

Consequently there can be no objection to the use of welding in this direction and the engineer's task is only one of plain common sense when it comes to choosing economical structural steel and to arrange the component parts in a suitable manner.

As regards load transmission, the lines of force within the material are at last under full control of the designer.

A few examples will serve as evidence for this fact.

Taking in succession the different motions: travelling, slewing, lifting and hoisting, there is no need to dwell on certain devices and arrangements which are already well-known and in current use and which will only be mentioned for the sake of completeness, so that the most desirable or novel features may be described more fully.

Among the parts which are now in general use and found in various mechanisms, one may mention:

Bearings.—These consist of rolled blocks, on which are welded flat plates forming lugs. The cap bolts may be welded studs or through bolts.

They may also be made with round bar sections bored to size and welded on plates sheared to any required shape and dimensions.

Levers and Rods of Every Description.—Consisting of flat strips and ties welded so as to form hinged fittings, or flat strips and blocks, or again flat strips and handles for control levers.

Simple Coupling Plates.—Consist of a round disc on which round sections are welded, forming hubs for keying.

Among special parts, it should be noted that: the travelling gear includes the wheels mounted on boggies, the different reduction gears and their housings, the transmission shafts and their bearings, the coupling sleeves, brake pulleys, etc.

The above-mentioned boggies were previously made of cast steel or riveted structural steel.

Castings were heavy due to the difficulty of casting parts of large size and small wall thickness. Riveted construction was only possible on flat surfaces and lacked rigidity.

The main or secondary boggies now form single and homogenous units. The vertical walls may be bent or forged without affecting the appearance or rigidity. The horizontal walls are curved and abutted to the lateral walls.

The necessary reinforcements for the pins are obtained by means of welded plates; stiffening ribs, both inside and outside, connect the faces, forming rigid frames, while leaving room for the mechanisms.

The wheels consist of a cylindrical hub on which two parallel ribbed webs are welded, on the periphery of which is fixed a rim of small thickness: 15 m/m. These parts are of mild steel (42 k. per mm^2) and consequently easy to weld.

The tyre was fitted hot and the appearance of the finished wheels is quite similar to that of the cast steel wheels which were in common use.

Fig. 4 shows these wheels seen from several angles. The travelling gears are of two types: spur and bevel.

The spur gear wheels have a plain web, on which the hub is fixed. The rim consists of a flat strip of 55 k. steel, bent hot, with the ends welded together. The teeth are cut without paying attention to the welded portion and it has been found that the whole was perfectly homogenous, without any appreciable difference at the weld.

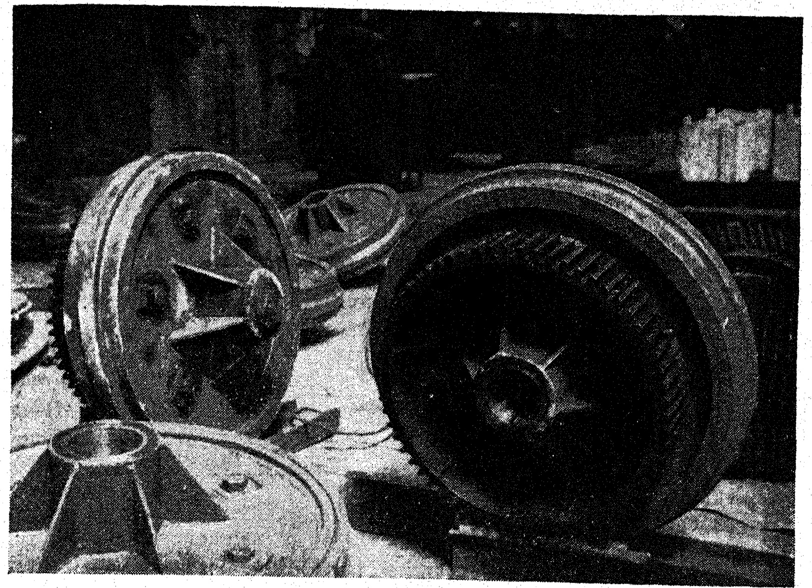

Fig. 4. Arc welded wheels.

Fig. 5. Arc welded bevel gear housing.

It should be noted, however, that the travelling gear has to withstand heavy, but occasional loads.

The bevel gear wheels are obtained in the same way as regards the hub and web but, due to the heavier section of the unmachined rim, forged crowns, turned and cut after welding, had to be used.

The gears are enclosed in housings forming an oil bath.

The bevel gear housings are of course fitted with bearings arranged for perpendicular shafts. The one shown in Fig. 5 is treble; note the bearings of the horizontal cardan shaft; the bearing for the vertical shaft is arranged within the housing, and the lubrication conduit visible on the photo feeds this bearing.

It may be noted that in addition to the simple and rational shape of this housing, it can also be made very strong due to the stiffening ribs and the stout fastening on the frame.

The driving gear housing is for spur gears and is constructed like the preceding one with sheet steel walls on which bearing blocks are welded.

The slewing gear, which is driven by a motor through a worm gear reduction, is an interesting welded job.

The motor is at the rear and drives the horizontal worm shaft. The upper bonnet is removable and permits the adjustment of the friction device, the worm wheel being loose on the secondary vertical shaft, and the limited drive being ensured through the friction coupling device. At

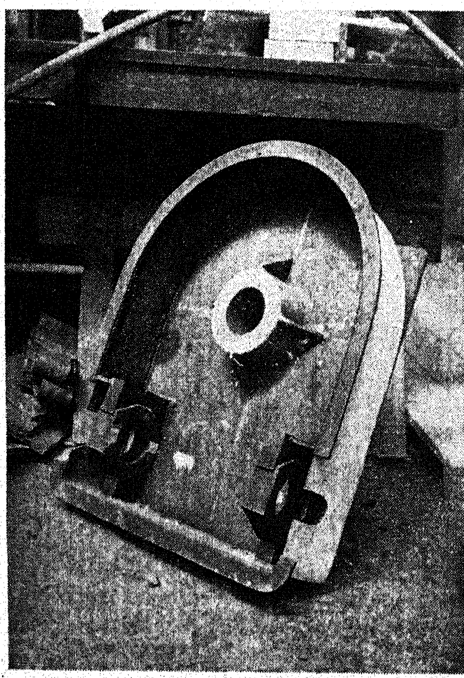

Fig. 6. Arc welded reducing gear case.

the lower end of the vertical shaft is keyed the pinion which engages with the spindle crown already described.

The reducing gear is constructed as follows: Fig. 6 shows the same type of work but of more recent construction.

Two horizontal and parallel plates of heavy gauge (20mm) are braced by webs and stiffeners forming, in plan, a square box, this system forming a solid unit.

On the upper plate are welded two bearing blocks for the primary horizontal shaft, one of the bearings being of larger size so as to accommodate the double ball thrust. At the center of the plate is welded a round bar for boring the secondary vertical shaft bearing.

The lower plate received a tube section for centering, which is plumb under the second vertical shaft bearing below the frame.

The side walls and cover plate are thin sheets, being only intended to ensure oil-tightness.

The use of electric welding has resulted in a remarkable saving and simplicity of design. It will also be noted that the worm bearing blocks include the housing for the bushing or thrust, inclined so that the worm may be removed without turning the wheel, while the teeth are disengaged from the thread.

This style of construction is also of interest for any other industrial use where worm reductions with a vertical secondary shaft are involved.

Hoisting mechanism is intended to handle an automatic bucket and therefore includes two drums, the rotation of which may be synchronized, or at different speeds, or in opposite directions, the synchronization being obtained mechanically through a clutch.

Each drum is therefore equipped with its own reducing gear and motor, but all gears are enclosed in the same housing.

Obviously, for a nominal power of 200 HP, the dimensions of the housing must be very large: 6 m. in length, 0.85 m. in width and 1.500 m. in height.

The housing consists of a rigid bottom trough with stout reinforcements at the bearings, the upper portion being made of thin sheets to prevent oil splashing.

The bearings are fixed on the longitudinal edges of the housing. They are removable and of the standard welded type. Oil tightness is ensured by means of joints with Beldam braid packing.

The pinions are solid, the gear wheels, which are either of the herringbone or spur type according to speed, consist of forged steel rims welded on punched and ribbed webs.

The holes in the webs are intended to avoid the noise produced by wheels revolving at a great speed.

The ribs consist of angles welded along the web edges. The general appearance is satisfactory, (See Fig. 7), as also the lack of vibration and noise.

The drum bearing brackets consist of blocks welded on ribbed plates. The cap is inclined on the horizontal, the height of center being as required by the circumstances.

The synchronization clutch is of the rocking shoe and radial action type and can hardly be described here. It should be noted, however, that the rim serves two purposes, the inside of the rim being used as a friction clutch and the outside serving for breaking the holding drum.

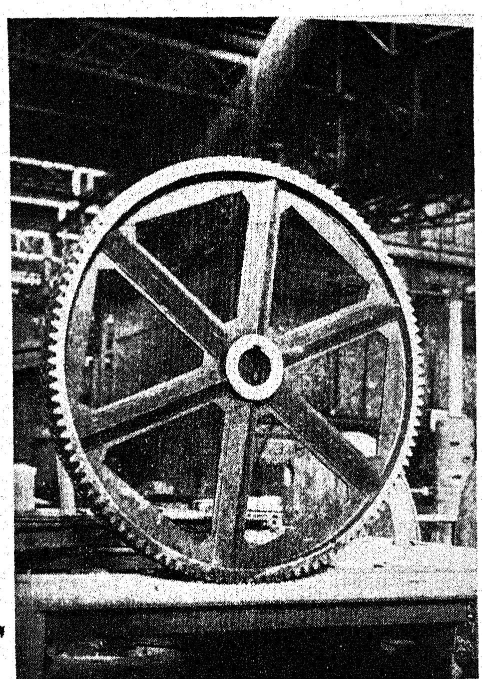

Fig. 7. Arc welded gear wheel.

The welding problem is therefore the same as for brake pulleys.

The brake pulley hubs, webs and stiffeners are made of mild steel (37 — 42 K. per mm^2). There is no difficulty in welding them. But if the same steel were to be used for the rim, the latter would be ruined very soon by the friction of the linings, which are slightly abrasive.

Moreover, the temperature rise on braking often reaches 300 to 400° C, and sometimes dull red heat.

The first brakes fitted with welded rolled steel rims were quickly worn out, as rolled steel wears more than cast steel and does not take the same polish as cast iron.

As regards wearing qualities, cast iron is ideal for pulleys, but it does not stand centrifugal forces.

An improvement in the wearing qualities of pulley rims had to be obtained by using 75 k. carbon steel, cold worked by milling after turning. Brake linings, whether dry or oily, having a pretty uniform friction coefficient, the pulleys were slightly lubricated with castor oil during the first few months of service until a polish coming close to that of cast iron was obtained.

This solution was adopted for the equipment described and no premature wear was noticed.

At present, the rims are made of 3% manganese hard steel, which seems to be preferable, but the problem of rim welding remains the same and rapid cooling must be avoided as well as a multiplicity of layers in order to avoid cracks.

The saving in weight amply compensated for the better workmanship required for such work.

The hoisting drums represent the only exception to the general use of welding. Drums were already available and it also appeared difficult to gain in strength or to save costs by abandoning the cast iron used hitherto.

The rate of fatigue in a drum is low, the dimensions of the cylinder are determined by wearing conditions and by the depth of grooving in function of rope diameter.

In any case the grooving has to be turned out of the solid and it comes out cheaper to lose a given amount of cast iron than of steel.

On the other hand, for other parts of the hoisting equipment, welded construction has been found of great advantage, in particular for cable deflector sheaves.

Deflector sheaves consist of a rim, spokes and a hub. The rim was formed with steel strip of suitable thickness, cold bent, the ends being joined by welding. The spokes, consisting of two angles arranged crosswise, were welded to the rim and to a hub of standard construction.

The machining of the rim was effected as follows: at the first stage, it appeared as a plain rectangle; at the second stage, the flanges were turned to size, but parallel to each other; at the third stage, the flanges were pressed, by means of a forming wheel, to their proper inclination.

The material used being ordinary mild steel, no difficulties were encountered in welding.

The advantages derived from this construction are therefore positive and the saving in material is as follows:

Cast steel sheaves serving the same purpose weighed................	230 kilos
Welded steel sheaves weigh..	90 kilos

which means a saving of 61%, with 12 sheaves per crane.

No other comment seems to be required, but it should be added that the static safety factor is equal to 14 in welded sheaves and that four of these sheaves are mounted at the top of the jib, that is to say plumb over the load. Consequently the dead load at the maximum radius is reduced by $(230 - 90)4 = 560$ kilos or 1/20 of the live load.

Jib Luffing Mechanism.—It includes a motor driving a set of spur gears enclosed in a housing.

The gear wheel consisting of a plain ribbed web, receives, keyed on its hub, a bronze nut engaging with the luffing screw. As the latter cannot revolve, the rotary motion of the nut is converted into a lineal motion on the part of the screw.

The housing has a removable front portion for dismantling and re-assembling. It is fixed on a frame which can oscillate around two perpendicular axes so as to follow the movements due to the inclination of the jib.

From a welding point of view, this mechanism does not give rise to any special difficulty.

Advantages and Conclusions.—The use of electric arc welding under proper conditions of design and application offers the main advantages which are at the source of all other desirable qualities, namely:

Economy and Safety.—The saving is very real for the builder who knows how to profit by the constant progress achieved in the welding field, in this sense that he wins over his conservative competitors, as well as for the purchaser who should have the benefit of technical improvements.

Philosophers say quite rightly that bilateral saving means general well-being, whereas unilateral saving means egoism.

Now, the builder derives the following benefits from welding: reduced weight as regards material used for main parts, no waste for minor parts; reduced time of fabrication, pattern making and foundry work being eliminated; reduced capital, no stock of patterns having to be kept; better use of material, by eliminating rivet holes which reduce the useful section of structural steel, and by allowing the designer full liberty in choosing the dimensions of mechanical parts. With cast iron or cast steel construction, it was in most cases necessary to use available parts, often too heavy or too weak; reduced general expenses, the value of stock material being smaller, as it now suffices to have standard plates, sectional steel, angles, ribbed sections, to be able to fabricate any structures or machinery parts at short notice; fabrication of parts adapted to determined loads or uses without being limited to a few standard types as in the case of cast iron or cast steel parts; possibility of constantly improving construction as regards both appearance and technique. It is now possible to abandon obsolete or unsatisfactory parts without increasing stocks and scrap.

The above advantages can only lead to reduced costs, thereby stimulating business activity.

On the other hand, it is obvious that the user will profit by: the reduction in purchase price; the amortization of the expense over a longer period, as welded structures offer a better resistance to destructive action, in particular to corrosion; reduction in maintenance costs, especially as regards the application of paint on plain and flat surfaces, the outside area to be painted being reduced in the case of tubular sections and gaps between members being suppressed.

As regards safety, the following points may be noted in favor of welded construction: the mechanical parts are perfectly homogenous, without such defects as are unavoidable with castings: blowholes, porosity, etc.; the lines of force may be strictly adhered to when determining the location of stiffening ribs and reinforcements; the area exposed to wind action can be reduced for sections of same strength as those used in riveted construction; the task of placing the neutral lines of framework members along the theoretical bracing lines is simplified; actual fixed connections can be obtained when assembling hyperstatic girders of the Vierendeel type, for instance; the strength is increased due to a greater rigidity of connections; the bounding observed on riveted structures with 54 k. steel is eliminated.

The latter points, which are very important, deserve a few words of explanation.

For constructing girders of the Vierendeel type, it is advisable not to be content with guesswork or empirical calculations for determining the moments, just as welding necessitates a thorough study in view of eliminating contraction effects and the size of the beads or fillets should

be perfectly determined in order to reduce or, better still, to compensate for internal stresses.

In the same way, for bracings, the size of gussets should not be excessively increased in order to reduce buckling lengths. By the way, a joint without gussets may be considered as a sufficient connection due to the continuity of members.

The excessive size of gussets represents an unjustified excess of caution, as the elastic distortions of the crane prove conclusively.

The deflections found are distinctly below normal, for 54 k. steel, as they are proportional to the fatigue rate, but are not reduced by an increased strength of the steel.

The theoretical deflection, for a simple cantilever beam, is given by the formula

$$f = \frac{P \times l^3}{3 E I}$$

where P is the load — I The moment of inertia of the beam

l the span — E the modulus of elasticity (22.000)

Considering that the bending moment is equal to $P \times l$ and that the fatigue rate $R = \dfrac{P \times l}{\frac{I}{V}}$ V being half the height of the beam,

the formula may be converted to $f = \dfrac{R \times l^2}{V \times 3E}$

The deflection f is thus proportional to the fatigue R and consequently the distortions of structures made of 54 k. steel stressed at 13 k. per mm^2 are 30% higher than for structures made of 42 k. steel stressed at 10 K/mm^2, as the modulus of elasticity is practically a constant for all steels.

However, the distortions on the jobs described are smaller than for 42 k. mild steel.

It must therefore be admitted that, in spite of the small size of the gussets, welded joints represent stiffer connections than riveted joints with longer gussets.

This explains the suppression of bounding in welded structures made of 54 k. semi-non-oxide steel.

Builders who had used this steel noticed that, due to the increased deflection, girders rebounded every time the action of moving loads was modified.

Apart from the unpleasant sensation felt by the operators, the excessive and sudden distortions caused rapid and general dislocation due to the loosening of rivets.

This was rather disquieting.

Now it has been proved that this defect is eliminated by the use of welding.

Is it necessary to draw the conclusion, knowing that these cranes have been in continuous operation for the better part of a year without any trouble whatever?

Chapter XI—Motor-Truck Winch of Arc Welded Design

By C. B. CURTISS,
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The design for a motor-truck winch, covered by the description in the following pages and by the drawings, Figs. 1 and 2 has been made to supply a wide field of users with a light-weight winch, of maximum strength, greatest safety, and at the least cost commensurate with these requirements.

The design avoids troubles that occur with the conventional winches whose main parts are made of cast material, and whose drums are supported directly on a through shaft which has to carry the bending and the torque loads.

Few articles are submitted to such abuse as winches mounted on motor trucks. A very great excess of driving power is always available, many of the users fail to show reasonable judgment, and there is always a temptation to try to do the work easily without protecting the winch against unreasonable overloads. Loading excessive loads in the oil fields, pulling poles out of the ground without loosening, moving heavy buildings or machinery with an indefinite friction load, and pulling wrecked trucks back on the road, all these services are apt to cause heavy overloads, even with the best of care and attention. Some users even make short pulls off the side of the truck, setting up a bad end thrust on the drum. Added to all these possibilities is the further problem encountered solely on motor trucks of the weaving of the chassis when the truck is on uneven footing, causing twisting in the winch which can easily of itself cause failure unless properly provided for.

The design offered avoids these troubles, or meets them with the least expense. Welding is solely to be credited with the success in making a design of lightest weight, of good safety factor, at a cost lower than the units now on the market. Materials are low in cost, are fabricated economically, and will not suddenly rupture, even when excessively loaded. This assures safety to the operators and to the loads being handled, for sudden rupture occasioned by "flaws in the casting" can not occur in the design submitted. Vital parts are easily and economically given an extra strength by merely making the material slightly thicker exactly where needed. Where it is a matter of life, as is often the case, our twenty years of truck-winch experience have proven that assured materials and best construction are essential. Besides these essentials, when low cost is needed, there is but one solution—welded construction.

General Description of Winch.—The proposed winch is designed for motor-truck mounting, and consists of three main parts:

1. A base with two welded supports for carrying the drum.

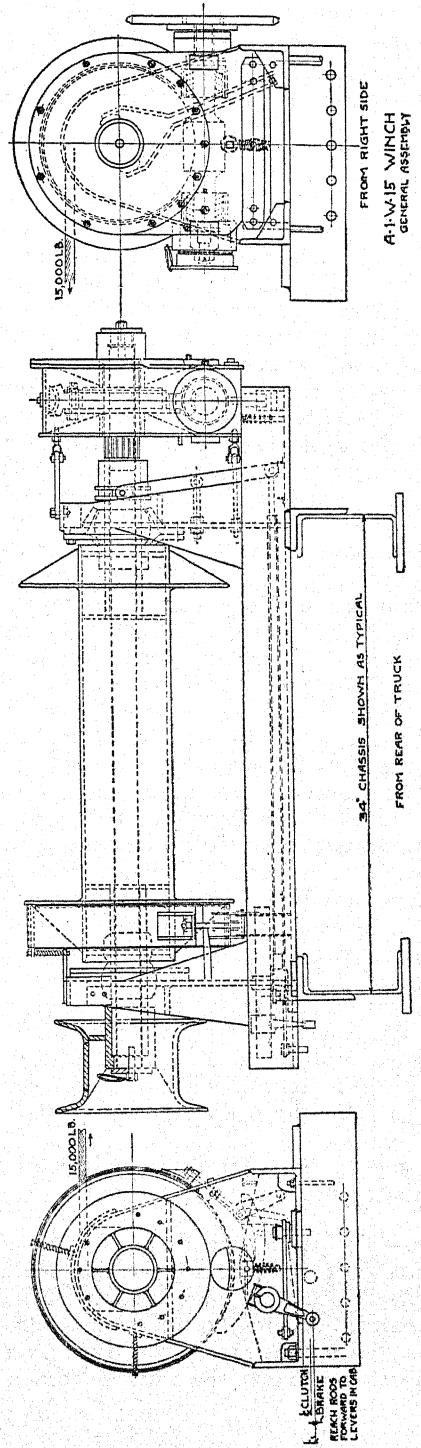

Fig. 1. General assembly of arc welded motor-truck winch.

2. A welded drum, driven from one end and supported on self-aligning bushings in the two supports.
3. A welded worm case, with the worm wheel center for driving to the drum.

These main portions are described below, together with the smaller connecting parts.

1. Base.—The base has two angles to extend across the chassis back of the cab, the front angle to be securely bolted down to the respective chassis side members. When pulling, these front bolts will take practically all of the strain. The rear angle is bolted down with lighter bolts, to prevent rattling, and to resist what load may be put on the niggerhead when pulling forward beside the cab.

To these two angles are welded web plates and gussets forming the end supports for the drum. The webs and gussets make angle and tee sections to carry the drum loads down to the base angles, and are figured to give an extra safety factor, preventing failure that might endanger operators. This is easily accomplished by a slight addition of inexpensive material.

To these end supports are bolted steel plate bearing supports, made to pillow bronze, spherical, drum-supporting bushings in a light bed of hard, poured, bearing metal. The spherical bushings care for the weave of the chassis, and prevent binding which causes stresses whose intensity is very hard to determine if the structure is rigid. The bushings are finished to close limits on the outside, as well as in the bore, and the plate supports are poured in a jig to permit replacement of any part. The only motion between the bearing supports and the spherical bushings will be that caused by weave of the chassis, all operating wear coming on the cylindrical bore of the bushing, where it supports the drum extensions, later described. A dowel, also used to carry lubrication to the bushing, prevents the turning of the bushing in the poured seat.

The bearing supports are strongly bolted to the web plates, and also tie together the front and rear portions of the end supports. Assembly variations are cared for by shims. The gussets are designed to take any end thrust that may be put upon them.

At the worm case end are two lugs to which are attached so-called "torque bars" that oppose the torque reaction of the worm case by imposing, mechanically, a couple. Torque can be fully opposed by such a couple, leaving no residual radial load on adjacent bearings. The weight of the case and contents is taken by a light spring. This lowers the friction and so helps the operator when pulling off a rope from a free drum.

At the brake end are operating levers and their supports, and also the support for the anchor for the drum brake.

2. The Drum.—The drum is made of 6″ pipe of any reasonable desired length (not over 40″) to suit the distance between the end supports of the base. Thus, for the centers of 32″, the stress due to bending will be only 14,100 lbs./sq. in. when pulling the rated load of 15,000 lbs. on a rope in the center of the drum; and, when operating on the bare drum with a radius to the center of the rope of about 3½″,

the stress due to torque will be but 3,090 lbs./sq. in. Thus, the combined stress will be less than 15,000 lbs./sq. in.

A brake drum, with a protecting flange to prevent rope damage to the brake band and with gussets to oppose end thrust, is welded near one end of the drum. A plain end with gussets is welded at the other end, leaving between the two flanges a rope drum. The end of the rope is fastened to the brake drum. The flanges are 15" O.D., giving a capacity sufficient for 720 feet of 5/8" wire rope. This is ample for all ordinary needs, and can be increased by the use of special, large flanges.

Each end extension of the drum is of seamless, heat-treated, alloy steel tubing, about 2 9/16" O.D. x 1 7/8" I.D. x about 12" long. On the outside of the inner ends of these extensions are welded 1/4" thick discs about 6" O.D. About 3 3/4" from the inner ends is welded on each extension a short tube about 3 1/2" O.D. x 1 3/4" long, the weld being at the inner edge only. The assembled extensions are then welded by jig into the 6" pipe drum, covering the outside of the center tube, and the inside of the pipe, with thin fiber tubes to avoid shorting of the electrode when making the intermittent inside weld of the 6" discs to the pipe. After this is welded, a disc 6" O.D. x 3 1/2" I.D. x 3/8" thick is strongly welded between the sleeve and the inside of the pipe.

The 12" long tube at the bushing location at the worm case end carries both torque from the worm case to the drum and bending from the drum through the spherical bushing to the base. The section modulus in bending is only half that in torque, and therefore where the two loads are concentrated it is undesirable to weaken the alloy tube with a weld. The sleeve thus supports the tube where the bending stress is high, and the torque only is carried from the tube through the weld to the sleeve, then from the sleeve through a heavy weld to the 6" x 3 1/2" x 3/8" disc, and thence to the drum, the weld from the tube to the sleeve being far enough away from the point of maximum combined stress to avoid objectionable weakening.

For the sake of uniformity, the opposite end of the drum is similarly assembled, though no torque is encountered. The inner discs stiffen the pipe against any chance of collapse.

3. **Worm Case.**—The worm case is of all-welded construction, to give maximum strength with least weight. The outer shell is of rolled and formed steel 3/16" x 4 1/2", and the bottom is of the same material, bent in a brake in the shape of a wide "U". At either end of these two pieces are inserted through proper holes short tubes to finish 3" I.D. with 3/16" wall by 2 1/8" long. These tubes support the outer raceways of bearings which in turn carry the worm. These tubes, with the shell and the bottom, and also the lugs for support of the torque bars (later described) are all welded together thoroughly in locating fixtures.

One side of the case has an opening about 10 3/4" diameter, through which the worm wheel can be placed in the case. This side is next welded to the parts mentioned in the paragraph above. The other side of the case has braces and a small tube to support the worm wheel center bushing. The braces and tube are welded on first, and then the side is welded to the balance of the case, access being had through the large hole of the other side, some of the welding being done on the outside.

All these welding operations are made in locating fixtures. The worm case is stress relieved before machining.

The worm is slightly less than 3″ outside, so it can be inserted endwise through the short tube supports. The outer raceways can then be put in, and then the bearings. A cover, piloted in the large bore of the case, closes this opening, having in the center, as described in the case, a small tube to support the worm wheel center bushing, with braces to carry the end thrust. This cover is also stress relieved.

The thrust of the worm is taken in a small housing at the end opposite the driving end of the worm. This housing is made from a 4″ XXH pipe with lugs welded to the outside, the lugs to be machined to fit in slots in the sides of the worm case. The sides of the case will extend beyond the case proper, and are slotted, and reinforced on the outside, so that the thrust of the worm is carried directly to the sides of the case, the reaction of the worm wheel center also being taken directly in the same two side members. The cover for the thrust housing is machined from a 3″ XXH pipe, with a light cover welded on the end. The thrust housing is assembled with the lugs vertical, and then is rotated 90 degrees to engage the thrust lugs in the slots of the case, turning to a small stop welded on one side. A cap screw on the other side is inserted to prevent rotation out of engagement. Packing is placed between the tube extension for the worm and the thrust bearing to prevent leakage. As there is no operating motion here, this may be packed tightly.

The sides of the worm case are of ¼″ plate, flame cut to proper outside contour. The inside is also flame cut, either for inserting and welding the short tube that supports the worm wheel center bushing, or for the large assembly opening. Proper braces, as described above, reinforce the inner side to take the side load of the worm wheel. This side load due to the helix angle of the worm, together with the friction of contact and motion, will be about 25% of the end thrust of the worm. A brace welded across the back side of the case stiffens the side between the edges of the formed shell near the worm. The cover reinforces the front side.

The cover is of slightly heavier material, with a short tube for the support of the worm wheel center bushing, similar to that in the inner side of the case. This cover pilots closely in the assembly hole of the case, is well braced, and is bolted securely to the case.

Bushings and collars carry the radial and thrust loads of the worm wheel center to the worm case and cover, with balanced and symmetrical forces that assure proper worm and wheel contact for the life of the unit.

The worm wheel center is fabricated symmetrically so that it may be assembled either way. The reason for this is to be sure that the pressure of the worm wheel against the center will always be a thrust against the flange and never a pull on the bolts. Thus, with a left hand worm and wheel, the flange will be toward the drum; and, with a right hand worm and wheel, the flange will be away from the drum (these conditions with the case on the right side of the chassis). The bolts can easily carry the torque load, but if the pressure due to the helix angle of the wheel is on the bolt heads, there is apt to be a slight set

in the bronze of the ring that will cause working, and trouble. The bore of the worm wheel rim pilots on the shoulder of the center.

The center is made of a piece of alloy tubing similar to that of the drum extensions. To this tube is welded a 3/8" disc 8 1/4" O.D., the inner face about 1/2" off center, to bring the wheel central. (The web of the wheel is about 1" thick). A ring of 6" pipe is welded to the 8 1/4" disc, the ring being long enough to extend slightly over a 6" disc that is located about 7/8" off the center line of the wheel in the opposite direction, for symmetry.

Both ends of the alloy tube are splined to fit a 2 1/2"-16A SAE spline, except for a slightly shallower tooth. The end of the drum next to the worm case is similarly splined, and a broached clutch ring may be slid over the drum extension alone for disengagement, or may be half on the drum extension and half on the worm wheel center when the drum is engaged for driving. The clutch ring has two rings welded on the outside, between which a shifting fork acts to engage or disengage the drum.

The outer end of the worm wheel center engages the main shaft by a short broached ring, similar to the clutch ring but without the shifting provision, with a small splined and broached spacer, the spline on the outside of the spacer fitting the ring, and the broach on the inside of the spacer fitting a 1 3/4" spline on the main shaft. This supplies torque only to the shaft that extends through the winch to drive the niggerhead.

The worm wheel center has a 1 3/4" I.D. steel bushing, 1/4" long, in each end to center the main shaft. The splined drum end has a 1 3/4" I.D. x 3/4" long self-lubricating bronze bushing at the end, to line the two splines. The steel bushings have no motion, and the self-lubricating bushing merely supports a small part of the worm case weight, motion occurring only when the drum is still and the shaft turns. Most of the weight of the case complete is taken off this bushing by means of a spring under the case.

The drum end away from the worm case is ground to a smooth and accurate finish, and on this is a bushed niggerhead, the bending load being taken on the drum extension, and the torque being supplied by the main shaft. The niggerhead is made of a piece of 6" pipe with two pressed flanges welded to it, and is driven and supported by a disc web with six ribs to stiffen it. The hub is made of 3" XXH pipe, bored for the bushing, and splined in the end to be driven from the main shaft in a way similar to the drive to the shaft from the worm wheel center. A washer and cap screw at each end of the main shaft holds the assembly together. Shims are used to adjust for variations in overall length.

The brake follows designs that have proven excellent on our winches. Torque is taken at an anchor at the bottom, the engagement is through an arm and reach rod that draws the two ends together, giving nearly 315 degrees wrap of the brake against a pull of the rope. The brake is adjusted for clearance at the anchor, at the operating lever, and at two intermediate points on the circumference. When released, springs keep the brake free of the drum. The anchor bracket is welded to the brake band, as are also the engaging ends. At the intermediate

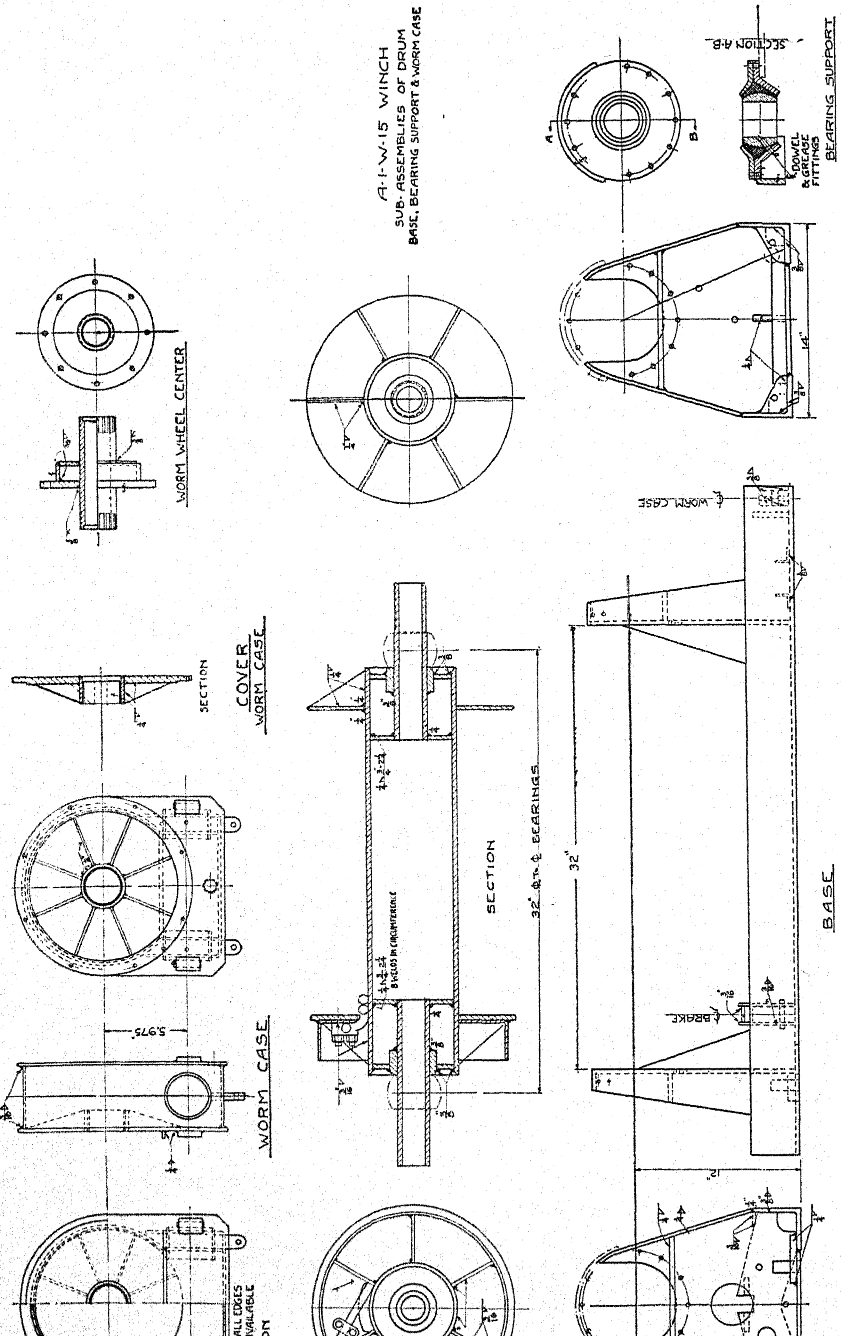

Fig. 2. Sub-assemblies of arc welded motor-truck winch.

adjusting points, a small ledge is welded to the edge of the band, permitting the use of a spring and cap screw without interference with rolling or forming the band. The adjustment at the anchor is by a bar rocking on a pin in the anchor support. The anchor support consists of two bars welded between the two base angles, having slots at the top and flat bars on edge to engage the 1″ square anchor bar. Through the center of the square bar is a ½″ pin, taking shear only, the 1″ square bar taking any bending, and allowing motion with good bearing.

The worm case is supported by "torque bars", again following successful practice. They are flexibly mounted so that an infinitesimal rotation of the case sets up two forces, one tension and the other compression, equal, opposite, and non-coincident. These forces, therefore, form a perfect couple, and oppose the torque of the worm case. The attachment to the worm case, referred to above, is through two lugs that are welded through the bottom of the case, to the vertical ends of the outer shell, to the tubes supporting the worm, and to the outer bent-up ends of the bottom of the case. These lugs are in the plane of the worm and wheel, so all loads are balanced and are equal about the center line. This avoids any unequal torque loads in the case itself that would tend to put the worm and wheel out of proper alignment. Wear of supporting bushings is compensated for by the flexibility of the linkage.

Links between the worm case and the end frame avoid misalignment of the worm and wheel in case of bushing wear in the case, and also locate the case and maintain clearance between the worm wheel center and the drum extension end.

Reach rods from the brake shaft lever and from the clutch engagement lever carry forward to the side of the chassis in the cab, where the hand levers are usually mounted so that the operator may control the winch from the seat of the truck.

The drive to the winch is by roller chain and a sprocket mounted on the driving end of the worm. A "floating idler" is available which relieves the worm of bending load, and also eliminates the tendency of the pull of the chain to cause the worm case to rotate. The idler also provides simple means for tightening the chain, and avoids chassis interference. It also makes possible a "Line Tension Indicator" that gives a reading of the rope pull during operation. This is accomplished by reading the torque output of the worm case, (by reading the load in one of the vertical torque bars), and correcting for the radius of the rope.

A non-reversing mechanism may also be supplied in connection with the torque bars and the idler, the torque bars applying a brake in proportion to the load on the case, and the idler releasing the brake when either raising or lowering the load. This eliminates wear on the mechanism, and provides an automatic brake to hold the load. These features are obtainable with this winch, and add greatly to its value to many users.

Another alternate that will be offered is to replace the spherical bushing with self-aligning ball bearings, to support the drum. Due to the lessened bending arm at the support of the drum, the strength of the ball-bearing unit will be about 20% greater. No other winch is so equipped or offered, so it seems best to follow the general practice

for the sake of competition, with the better unit available at an extra price.

The fact that with the short bending arm the drum extension may be 2$\frac{9}{16}$" O.D. means that there will be less friction to overcome when pulling off a rope from a free drum than when doing the same thing on the conventional winches, which, because of the construction, have to have larger shafts. For a given load on a bearing, the friction torque is proportional to the diameter.

Comparative Advantages.—1. Proportionate cost savings, in percentage, of the design described over previous designs and previous methods of construction.

For some ten years, we have built a steel winch of forgings and riveted construction along similar lines. It has gained an enviable reputation for strength and service, but the cost has been excessive, and the result has been the loss of considerable business to inferior designs. In comparison with the previous design, the proposed welded winch shows major savings of material and labor, as given below:

	Previous Design	Proposed Design	% Saving
Material cost	$140.71	$88.66	37
Labor hours	77.3	29.53	61.8

Included in the material of the two designs are items which are unaffected by the redesign, such as the worm, worm wheel and bearings, the operating levers, the sprockets, and the driving chain. These items total to a cost of $52.36, and are the same in both cases. Thus, the redesign has really made a considerably larger percentage of material saving on those parts that are affected by the change. If those items not affected are deducted from both material costs, the comparison is as follows:

	Previous Design	Proposed Design	Saving %
Affected material	$88.35	$36.30	59

A complete cost estimate follows. The result is that the high quality and high strength can be offered to the trade at prices competing with the inferior units now on the market. The worm and wheel offered are supplied by one of the recognized best-quality producers who cannot sell to either of our larger competitors because of price, although the cheaper of the two competitors could doubtless improve his quality by so doing.

The support of the drum by two end frames avoids the necessity for a heavy main shaft, as explained, and the main shaft carries only the torque load that is needed to drive the niggerhead. Thus the 1¾" shaft that extends through the drum from the worm case to the niggerhead needs to be merely of cold rolled steel, as the stresses are very low when torque only is carried. Beside driving the niggerhead, the only other service of the main shaft is to keep the worm case and the drum in line so that the clutch will shift easily. The ends of the main shaft and also the drum end and the worm wheel center are all splined. This gives an inexpensive though very strong method of driving, and, be-

Estimate of Cost

ITEM	Weight per Winch		Mat'l Cost Including Gas & Rods	Flame Cutting			Arc Welding			Fit Up & Clean Hours	Machining Hours	Total Hours
	Gross Lbs.	Finished Lbs.		Ft.	Gas	Hrs.	Ft.	Rod Lbs.	Hrs.			
Base	122	117	$ 4.41	20	$0.24	.28	26	6.6	.95	.3	1.08	2.61
Bearing Supports	45	42	5.00	8	.10	.08	3	.6	.10		1.29	1.47
Brake and Clutch Sub Levers	14	14	1.55	2	.03	.17	2.35	.45	.24	.03	.73	1.17
Drum	128	116	7.38	22	.17	.42	23	4.8	.75	.2	1.88	3.25
Brake Band, Complete	19	18	2.11	5.5	.04	.12	6	1	.25	.05	.71	1.13
Worm Case and Torque Bars	53	53	2.91	15	.18	.51	28	5.6	.75	.25	2.29	3.80
Worm Case Cover and Bushings	18	17	1.88	8	.06	.30	8	1.6	.25	.05	.58	1.18
Worm Wheel Center and Thrust Hs'g	27	21	1.75	5	06	.12	7	1.8	.37	.26	2.71	3.46
Worm Case Drive Parts	40	40	35.20								.20	.20
Main Shaft	30	30	1.05								.60	.60
Washers, Driving Spacers and Rings	9	6	.51	1.5	.04	.04					.40	.44
Niggerhead	33	26	1.88	10.5	.09	.42	14	3	.35	.25	.90	1.92
Clutch Collar	8	7	.67				2	.5	.05	.05	.15	.25
Brake Adjusters—Case Links	4	4	.50			.02		.1	.02		.06	.10
Misc. Mat'l & Ass'bly Hours	10	10	2.50								3.00	3.00
Levers for Cab	20	20	6.16	2	.01	.05					.41	.46
Reach Rods	8	8	1.06				.1		.05	.04	.20	.29
Sprockets and Roller Chain	25	23	11.00								.70	.70
Bumpers—Bolts, etc.	36	36	1.14	4	.07	.12	2	.4	.10		.28	.50
Contingencies											3.00	3.00
Totals	649	608	$88.66	103.5	$1.09	2.65	121.45	26.45	4.23	1.48	21.17	29.53

cause of the balanced drive, does not require fitting as is the case with a keyed shaft. It also makes assembly and servicing far easier, and avoids many repairs needed on the other type.

The splining of the shaft and worm wheel center ends may be done on a simple milling machine, using two saws or narrow cutters, with a spacer between. This results in a spline that retains its full width for the full length of the tooth, and also avoids the expensive cutters or hobs usually used for this duty. Operators are willing to force the cheap cutters, and the result is that the time of splining two ends of the shaft or center need not exceed 1/4 hour to .3 hour at most. This has been done in ten minutes. The spacers may be splined in 1/10 hour each, or less. Broaching can be done at not over 10¢ each.

It will be noted that the operations on the parts of the winch are essentially simple, that when welded the finish may be light, that the material will be easily worked, and that the weights to be handled are light. It is in this way that the best equipment can be offered at the best price.

The worm case is assembled on a fixture, so that it is possible to finish the bore for the wheel center and the worm by one light cut. This lessens material purchased as well as labor performed. Castings will vary more, and therefore the material to finish off costs more in the first place and causes much more labor to finish. The design of the thrust bearing housing independent of the worm case allows accurate work on this part to be done quickly and cheaply in a lathe, and avoids the need for an expensive boring mill. The slotting of the case can be done in a simple milling machine.

The clearance between the mainshaft 1¾" O.D. and the inside of the drum extensions 1⅞" I.D. does away with the operations of boring the drum ends, except for a very short distance in the splined end. The use of pipe for the drum barrel will give longer life than castings, as rope abrasion is less on rolled steel parts. This also avoids the necessity of machining the barrel.

2. The gross saving accruing to industry through the general adoption of the design.

This item is dependent on at least three factors, some of which can be evaluated in dollars, and others are comparatively intangible. The factors that largely determine the saving, with the substantiation of the figures below, are:

a. The number of comparable units operating in a given year.......... 10,000

b. Savings due to less weight, greater strength, wider services rendered, increased safety and protection to men and materials, per year..........$1,137,000.00

c. Savings in first cost compared with items of comparable capacity and quality, per year..........$ 450,000.00

a. The number of units that are working in the industry at this time can be estimated only. The best information at hand is that in recent years about 4000 units have been sold annually, and it is safe to estimate that the number of units of comparable capacity still working is at least 10,000 units. The figures below are based on that assumption, which is conservative in view of the probable sale for units

in the future. The savings figured are on the basis of a change from the past designs to the proposed design.

b. The second item is made up of three classifications as shown in the tabulation below, with the respective data of substantiation following the tabulation:—

A. The saving due to weight alone results in \$43.75 per winch at a very low mileage assumption, or a total per year of	\$ 437,500.00
B. The savings due to greater strength should reflect in the repair bills and in less lost time for equipment. It is safe to assume this saving as at least \$50.00 per unit per year, a total of	500,000.00
C. Wider services, and protection to men and materials are intangible, but can be conservatively estimated at	200,000.00
Total estimated savings per year	\$1,137,500.00

A. Lighter weight is a direct saving to the owner, as the established cost per ton mile for trucking is approximately 5¢. The weight of the proposed winch, 608 lbs., is from 175 lbs. to 200 lbs. less than competitive units. Using the lesser figure of 175 lbs., this represents 7/16¢ per mile run of the truck. If the truck goes only 10,000 miles a year, this will represent an annual saving to the owner of \$43.75, increasing with the mileage of the truck.

B. The estimated saving due to the greater strength is based on the repairs we formerly had with our old conventional winches as contrasted with the repairs on the riveted design similar to this proposed design. This riveted design had been out for two years, with many reports of wonderful service, before a single repair was called for. The volume of repair business on these winches is still remarkably low, by far a majority of those built never having had any repair at all. The trucks on which winches are mounted are out of commission if the winch gives trouble, the whole equipment representing at least \$25.00 per day. It is safe to figure that the conventional design, similar to the early designs we offered, will have at least two days a year more lost time. This would mean \$50.00 on 10,000 units, or \$500,000.00 per year.

C. The third item covers more indefinite savings, as follows:

Savings in cable installations through the use of line tension indicators.

Savings to other concerns such as tree nurseries, wreckers, and machinery handlers, where knowledge of the pull is desirable and can be obtained with a line tension indicator.

Savings to all concerns by the lessened risk to operators, with consequent lost time and attendant expenses.

The intangible value of mere human protection to the personnel.

c. Saving in first cost should more properly be based on the probable sales of future units, rather than on the number of units in operation, as the comparison has more to do with the selling price of the proposed winch as compared with the price of competitive units now offered.

The redesign proposed allows the listing of the winch with all driving and mounting parts, a two-speed and reverse power take-off, connections, and a floating idler (the idler not supplied by others), at a price of $392.00 as compared with a price of $565.00 by our most substantial competitor, the prices being based on approximately the same percentage of profit, and the same discounts to the trade. Another winch of lower grade is offered at a lower discount at a list on the same items (without the idler) of $380.00. If the proposed unit were figured at that discount to the trade, the list would be $348.00. The floating idler and bumpers, which we alone include, cost $26.07 per winch. We prefer to assume this added cost in consideration of the advantages obtained.

Thus, if the basis of sale were to be that of the better competitor, and assuming the number of winches to be sold to be 4000, the annual saving in first cost would be

$565.00 — $392.00 = $173.00. This x 4000 = $692,000.00.

If the comparison were with the second competitor, the saving would be per year the sum of

$380.00 — $348.00 = $ 32.00. This x 4000 = $128,000.00.

The number of winches made by both is approximately equal, and as some other makers supply substantial numbers of winches at considerably higher prices to special fields which can be well served by our proposed winch, we feel that a reasonable estimated saving in first cost per year would be at least $450,000.00. This should be well justified in view of the unusually high factor of safety of the proposed winch. It is also known that the maker of the cheaper unit has had a good deal of trouble with items of the winch when it is overloaded. He can justly claim abuse, but the better makers try to care for the abuse without excessive costs to the users. The ratings have often been a measure of the conscience of the makers, rather than a proper comparison of mechanical strength. The design of the proposed winch is based on a desire to have the best and strongest unit, at the best price possible. Welding has made possible a price that is even better than the prices of inferior units offered.

3. Increased service life, efficiency, and general economy and social advantages provided.

The conventional winches as offered by competitors are built with one end frame and a worm case supporting opposite ends of the main shaft. A bushed drum is mounted on this shaft, and also a clutch for engaging the drum. The clutch requires considerable space, and this puts a heavy bending load in the shaft. The resulting deflection of the shaft is carried to the end frame and to the worm case. Deflection in the worm case will put up unknown strains, as well as endanger the proper meshing of the worm and wheel. The elimination of the deflection will ensure longer life, and in reality is equivalent to increasing the strength of the drive. The torque load from the worm wheel to the

drum in the conventional design is carried by keys in the shaft through the shaft itself, and the combined stresses are greatest at the points where the keys are located, thus having maximum loads at the weakest spots. The shaft in the conventional design often is the most expensive item of the winch, and also is the point of greatest weakness. In the proposed design, the extensions of the drum are supported directly in the end frames, with a maximum bending arm of 1¼". The stress in the driving extension is low, so that the operator has maximum safety. Also, the drum is supported directly in the two welded steel end frames, where extra material, cheaply supplied, gives an extra safety factor, eliminating danger of sudden failure of the structure. The conventional units are built with the drums, worm case, cover, and end frame, of cast material, which is never so sure as rolled steel, and the cast parts are more apt to fail and fail suddenly, with danger to the lives of the operators. Beside this, in the design submitted, the main shaft which passes through the drum is an added factor against serious failure.

While safety to the operators is most important, another substantial saving of material is possible by the use of the "line tension indicator" mentioned above. This has been successfully used in connection with the previous design of winch, but with the proposed unit the application will be far easier as the use of it has been contemplated in the winch design. This mechanism is applicable only to a design as proposed, as it reads the line pull by measuring the torque of the case, and correcting for the radius. When pulling high-voltage underground cable, the cost of which is often $3.00 per foot or more, a slight overpull is apt to cause a later failure of the insulation, with a substantial loss to the company, and a still more disagreeable reaction from the customers inconvenienced. It would seem certain that concerns using winches for such operations would certainly want to add an extra of about $15.00 to the list in order to get such insurance when handling expensive cable. The cost of one section of cable pulled successfully would outweigh several times the cost of the whole winch installation. This insurance is difficult to evaluate in dollars, but the companies seem always interested in getting such a device, especially if the cost of the winch so equipped is not excessive.

The savings due to lighter weight have been considered above. This saving may go still further by the application of similar principles to other parts of truck equipment, to an extent that may permit the use of lighter chassis for winch purposes.

The brake on the proposed unit will hold a load on the bare drum of 10,000 lbs., with the clutch thrown out, by pulling an estimated force of 35 lbs. on the hand lever in the cab. This is quite in contrast to the competitive units, which are sold with a brake but are not supposed to be able to hold any appreciable load with the clutch disengaged. In fact, tests on one of the higher-priced winches showed that the brake could hold only 1500 lbs. on the bare drum, the result being that the load could not be held while operating the niggerhead. That is the accepted method for the less expensive winches, and consequently the brakes on most other winches are not designed to hold any substantial load. Lowering is safer when driving the load down, but opera-

tion is easier if the brake is properly designed. Our proposed winch meets either demand.

The splined clutch has no tendency to become disengaged. The torque is evenly distributed around the circumference, and the difficulty with the jaw-type clutches, of having them throw out at crucial times, is avoided. There are stops for the extreme motion of the clutch shifter fork, so that it is impossible to keep a load on the shoes and cause wear in any position. Adjustment is made at the fulcrum. This assures long life and least maintenance of the shifter mechanism.

An angle with a welded-on bumper over the top of each side member of the chassis is not supplied by competitors, but it is a better design, and protects the chassis where it receives a heavy load. The angles are therefore included in the price of our proposed winch.

Summary.—The winch, as above described, has been designed in an effort to do what is usually impossible,—make a unit of the highest quality and strength for the least price. Thanks to welding, we feel that this purpose has been well accomplished, and that the description clearly proves such a contention. The unit is stronger than competitive units, lighter, and can be sold profitably at a lower list price, to a constantly widening field of users. Again let us restate the fact that this is due to the use of welded construction.

Chapter XII—Design of Propeller Type Pump for Arc Welded Construction

By Charles Beensen,
Engineer, Cocoa, Fla.

In 1934 the author became actively interested in water table control in Florida for agricultural purposes. Due to the general low elevation of the land, during periods of excessive rainfall, at times 12″ in 24 hours, the conventional drainage system is inadequate, the land becomes flooded resulting in destruction of crops due to rotting of the root systems and also due to scalding by the water becoming heated by the sun.

At other times there are periods of drought resulting in destruction of crops due to lack of moisture. This condition is particularly true in Florida in certain sections of the citrus production and winter vegetable crop areas.

During these rainy periods it is necessary to remove the water as fast as it falls, if possible, to prevent flooding, however, it is necessary to keep the water pumped out of the area under control, at times, as much as four feet below the prevailing water level adjacent to this area. On the other hand during a drought, dry or cold period it may become necessary to pump water onto the area under control.

Failure to control the water table and amount of moisture may result in a complete crop failure and in the case of citrus trees may even permanently damage and possibly destroy the trees.

The pumping equipment available to perform this type of work was costly, poorly engineered and fabricated, made too light and corroded rapidly, and generally broke down when it was mostly needed, was inefficient and used too much power, was poorly installed and repairs were expensive and delayed. These pumps were not flexible enough to be overloaded during the first part of the flood in order to keep the water level down.

Having observed these foregoing conditions I decided to develop and build a pump and driving unit that would be cheaper, more flexible, more dependable and capable of being easily and rapidly repaired in case of breakdown.

In April of 1937 plans were developed for a new improved propeller type pump. Construction on the first experimental unit was completed in July and the unit was installed in August of that year. It has given exceptionally good service since that time. Plans are under way for construction on a production basis.

This improved propeller type pump is a radical departure from conventional practice.

Referring to the diagram in Figs. 1 and 2, pages 1114 and 1116, you will note that the outer casing "A" is constructed of 3/8″ material, which may be purchased in casing form or be rolled from 3/8″ plate and electric arc welded longitudinally. The inner wheel casing "B" is

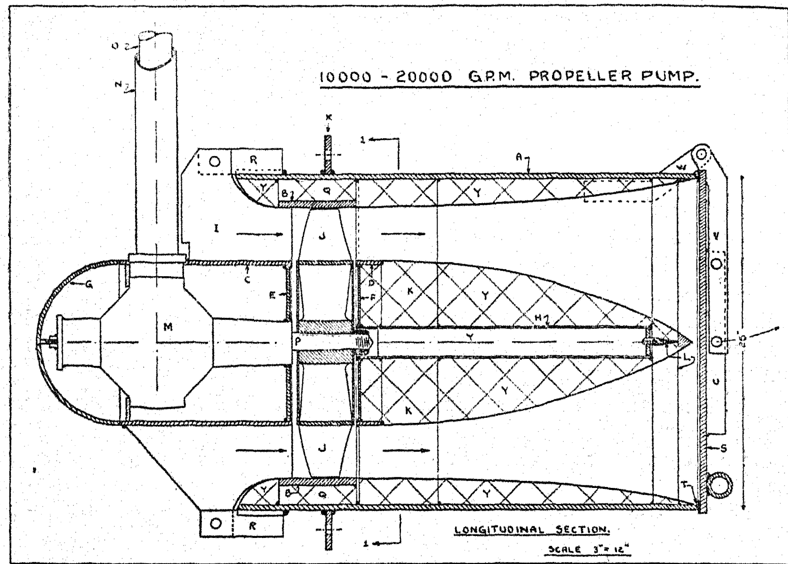

Fig. 1. Longitudinal section. 10,000—20,000 gallon-per-minute arc welded propeller type pump. (For legend, see page 1117).

constructed of 1/2" wall thickness steel tubing. This too could be rolled and electric arc welded longitudinally at a reduction in cost, however, it would require more machine work as the propeller must fit closely with very little radial clearance.

This inner ring is held concentric with the outer casing by means of spacing blocks "Q". These blocks are electric arc welded to both the inner and outer casings. Several small nuts are spot welded to the inside of the casing "A" to fasten the reinforcing material for the cement filler "Y". The discharge end of the casing is bronze faced "T" with the electric arc and then machined so as to make a tight seat.

The next part of the assembly is performed outside of the pump body. The inner casing discharge ring "D" is arc welded to the inner casing head "F", then tubular bracing "H" is arc welded to head "F". Discharge guide vanes "K" are arc welded to inner casing discharge ring "D" and onto tubular bracing "H", this assembly is now inserted into the pump body with the guide vanes "K" resting against inner wheel casing "B". Discharge guide vanes "K" are now arc welded to inner wheel casing "B" and onto outer casing "A". Streamline bracing "L" is now arc welded to tubular bracing "H" and onto outer casing "A". Support ring for mounting pump "X" is now arc welded to outer casing "A". On the inlet end of the pump the inner casing head "E" is arc welded to the propeller shaft housing and the inner casing "C". Inlet guide vanes "I" are arc welded to the inner casing "C". Angle fastenings for inlet guide vanes "R" are now arc welded to outer casing "A". On the discharge end of the pump, bracing on cover "U" is arc welded to cover "S". Bronze facing "T" is now applied to cover

"S" by the electric arc and then machined for a tight fit. Cover support members "W" are arc welded to outer casing "A".

All of the arc welding is now completed. By removing the unit "M" the pump body is ready to receive the reinforced cement filler "Y". This filler is finished to the proper contours by means of metal templates.

When this cement finish has set, the drive unit "M" can be set into place, it is held in proper alignment and securely fastened in place by having the inlet guide vanes "I" inserted into the inner wheel casing "B" for a distance of one inch and by bolting onto angle fastenings "R". The pump is now ready for installation, which may be made by bolting the support ring "X" to a wooden bulkhead or the outer casing "A" may be permanently set into a concrete dam.

By referring to Fig. 1 you will note the advanced design in this type pump over the conventional propeller pump. In the first place as the water passed straight through the pump no change in direction occurs. The pump is short and thereby offers minimum frictional resistance to the water passing through it.

The propeller hub is large, the work is done on the outer part of the wheel, tendency for radial flow is reduced, also pressure over blade section is more uniform, tendency for back flow near hub is eliminated.

The pump is so designed so that at full load the velocity head of the water passing through the propeller is equal to the pressure and velocity heads at the pump discharge.

The inlet guide vanes prevent any tendency to swirl and the discharge guide vanes take the swirl out of the water and change that part of velocity head into useful head.

You will note that the water passage through the pump is well streamlined, just before and after the propeller there is no change in section size. After the water leaves the propeller at high velocity the water section becomes larger thereby reducing the velocity and converting velocity head into pressure head.

The drive unit "M" has reduction gears mounted on timken bearings. By using reduction gears of 3.54 ratio the specific propeller speed is kept down which results in more efficient operation. The drive shaft speed is high which results in a corresponding decrease in torque, which is the same as that exerted by the engine driving the unit. The outer end of the propeller shaft is mounted on a ball bearing. The outer part of the propeller shaft is sealed by a double Garlock seal, which keeps the water out and the oil in. In operation the drive unit "M" and drive shaft casing "N" are filled with light oil. This oil pressure is equal to or greater than the water pressure. The drive shaft "O" normally revolves at 2,000 R.P.M. for the normal pump rating of 10,000 G.P.M. At those periods when large quantities of water must be removed and the head does not exceed two feet the drive shaft revolves at 4,000 R.P.M.

This drive shaft is mounted on ball and roller bearings. In order to get prompt and efficient service on this pump the units "M"—"N" and "O" are constructed of standard automobile parts. The unit is designed to be driven by a Ford V8 engine, which normally turns over at the same rate of speed the drive shaft "O" turns, however, any other type power unit can be used.

If anything should break down it is only a matter of removing 4 bolts and removing the whole drive unit and propeller assembly, and have it speedily repaired at any service station, or insert a spare unit.

The same way with the pump engine, repairs can be made rapidly, however, in case of real emergency, a similar engine can be removed from an automobile in a short time and put to work.

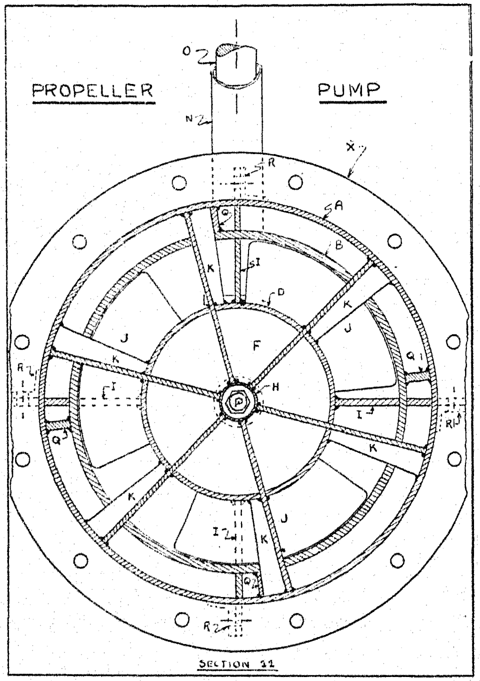

Fig. 2. Arc welded propeller type pump—Section I-I, Fig. 1. (For legend, see page 1117).

It is this feature of availability which makes this type of pump so valuable, as in many cases, the loss of a whole crop depends upon how rapidly the water can be controlled.

This type pump construction is only made possible by means of electric arc welding. It could not be made by another method of welding as there would be too much distortion. In the particular unit we recently constructed, we feel confident that we can construct pumps of this type for 50% of the price of competitive pumps for the same pumping capacities. In the conventional designs two or three times as much casing is used, which is of light material and corrodes on both the inside and outside. Long drive shafts are required, which are poorly mounted and not capable of high speed for emergency pumping. Water changes direction going through the pump and encounters excess resistance flowing through the pump. The pump is heavy and cumbersome, not capable of being easily and quickly repaired.

It is hard to estimate the gross savings accruing to the general adoption of the design of our new type propeller pump, however, for every dollar invested in a pump probably $10.00 or more can be saved during the life of the pump.

Since this type of pump is cement lined on the inside, and has an outer shell of 3/8″ material and a wheel casing of 1/2″ material it will outwear several conventional type pumps. By facing the end of the casing and the check valve cover with bronze, corrosion is eliminated and tightness assured. The guide vanes are constructed of copper bearing steel. The propeller shaft and propeller are constructed of either bronze or monel. The bolts holding the drive unit "M" to the casing are either bronze or monel. The hinge pins on the outlet check valve are monel running through bronze bushings. The whole pump as a unit is built to have a long serviceable life.

This pump is efficient in operation and is designed and constructed to operate at high speeds and capacities, all of the mechanical parts are constructed of alloy steels.

By means of this type pump, properly installed and operated, hundreds of thousands of dollars can be saved for the producer, and this in turn is saved by the ultimate consumer.

I wish to again repeat, without the aid of electric arc welding the construction of this type of pump would be impossible, as there is no other method available to manufacture it.

LEGEND PERTAINING TO FIGS. 1 AND 2

A.—Outer Casing. B.—Inner Wheel Casing. C.—Inner Casing, Inlet End. D.—Inner Casing Discharge Ring. E.—Inner Casing Head, Inlet End. F.—Inner Casing Head, Discharge End. G. Streamline Cover Over Drive Unit at Inlet End. H.—Tubular Bracing. I.—Inlet Guide Vanes, Torsion, Thrust and Alignment Members. J.—Propeller Blades. K.—Discharge Guide Vanes. L.—Streamline Bracing. M.—Drive Unit. N.—Drive Shaft Casing. O.—Drive Shaft. P.—Propeller Shaft. Q.—Spacing Blocks. R.—Angle Fastenings for Inlet Guide Vanes. S.—Cover at Discharge End of Pump Which Acts as a Check Valve. T.—Bronze Facings on Outer Casing and Cover. U.—Bracing on Cover. V.—Cover Support Linkage. W.—Cover Support Members. X.—Support Ring for Mounting Pump. Y.—Reinforced Cement Filler.

Chapter XIII—The Welded Deep Well Turbine Pump

By Fred F. Burya,
In charge, pump drainage operations, lower Columbia River,
U. S. Army Engineers.

A number of years ago the writer had occasion to visit an engineering project where an inverted siphon was being constructed under a river in the state of Washington by the United States Reclamation Service. During this operation, the river broke through, flooding the uncompleted tunnel, thus making it necessary to unwater the siphon tunnel before operations could continue and the project be completed.

It was found that the seepage into the siphon tunnel was rather large, making it necessary to install a large pumping unit for unwatering operations.

Because of the nature of the job, it was decided that a deep well turbine pump was best suited for this unwatering operation.

However, it was found that no turbine pump of the capacity required was manufactured at that time in the United States. Therefore, the United States reclamation service advertised for bids for the designing and construction of a deep well type pump with a capacity of 25,000 G.P.M. (This pump was of cast iron construction.) Only two pump companies put in bids. The job was let and after considerable loss of time, the pump was made and the project carried on to completion.

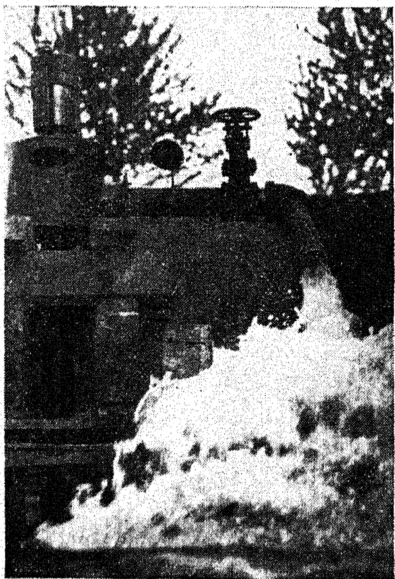

Fig. 1. Arc welded turbine pump in operation.

One can readily understand that the cost of this special designed deep well turbine pump had to be expensive, although it was most economical for the service required.

The above example brought to the writer's attention the need of a method of construction for deep well pumps which would not only reduce the cost of such equipment, but would also save time in construction, especially for special design units.

With this in mind, the writer drew up plans and constructed a welded 12-inch deep well turbine pump. (See Fig. 1) This unit was designed for the following requirements:

(1) Pump was to operate in a 12-inch diameter well
(2) Pump capacity to be from 800 to 900 G.P.M.
(3) Pump to operate at a total head of 25 to 30 feet
(4) Pump was to have a belt-drive so that it could be driven by a tractor and used for irrigation or other purposes
(5) Pump column was not to be over 20 feet in length

Upon completion of this pump, the unit was set up for test with an electric motor drive in order to facilitate the calculation of the power input. A weir box was constructed, using a 2-foot contracted weir. Head readings were made with a calibrated 6-inch altitude gauge. Weir measurements were made with a hook gauge.

All calculations for friction head and velocity head were made in accordance with A.W.W. standards.

The aforementioned test and experience of designing and constructing the welded 12-inch deep well turbine pump has convinced the writer of the feasibility of such construction and has proved that such welded construction has numerous advantages over the conventional cast iron deep well turbine pump. Following are some of the outstanding advantages of the welded construction over conventional cast iron construction:

(1) The welded pump makes possible a design to suit pumping conditions, thereby making for higher efficiency for each individual case.
(2) The welded construction eliminates delays resulting in pattern making or casting.
(3) Welded construction makes possible the use of special materials economically in the construction of diffusor or other pump parts to prevent wear when pumping corrosive and abrasive charged liquids.
(4) The welded pump is lighter in weight and is stronger than the cast iron pump.
(5) The lighter weight of the welded pump will reduce freight cost and will make for easier installation.
(6) The lighter weight of the welded pump will permit deeper settings and will enable its use against higher pumping heads.
(7) The welded construction makes possible larger port openings through pump and therefore greater capacities for a given size of pump.
(8) The welded pump may be of smaller diameter for a given capacity than is possible with cast iron construction due to larger port areas.

(9) The welded pump reduces cost of construction, especially where special construction is required, since no large patterns and castings are required.

(10) High efficiency in the welded pump is possible because of smoothness of the steel plate used in its construction. This is impossible with cast construction since it is impossible to finish the surface water passages through the pump.

(11) The greater strength of the welded pump makes possible the use of more stages and higher pressures than is possible with cast iron construction.

(12) The welded construction is feasible for both large and small units.

(13) There is less machinery necessary on the welded pump.

(14) A large stock of different diffusors is not necessary because the welded construction makes it possible to exactly meet pumping conditions encountered.

(15) The welded pump may be built anywhere as no special machinery is needed. Any plant where plate forming and welding equipment are available can manufacture the welded pump.

(16) Expensive pattern and core box costs are eliminated by the welded pump construction.

COST WELDED CONSTRUCTION

12-inch single belted head deep well turbine pump with 20-feet of 6-inch O.D. column shaft, bearings and oil tube.

Part Name	Wt. of Plate, Plus Wt. Welding Rods Used Lbs.	Cost of Steel Plate Used (less scrap) @ 6c lb.	Cost of Cutting Gas	Cost Welding Rod	Total
Belted head	109.5	6.57	.264	.381	7.215
Discharge head	188.0	11.28	.550	.920	12.750
Top diffusor	52.7	3.16	.210	.550	3.920
Suction case	27.2	1.63	.140	.320	2.090

LABOR and OTHER COSTS

Forming 16 man-hours @ \$1.00 per hr.	\$ 16.000
Welding and assembling 16 man-hrs. @ .80	10.400
Machining 24 man-hrs. @ .80	19.200
20 ft. Std. 6" O.D. column complete with shaft, oil tube and bearings @ \$2.00 per ft.	40.000
Mandrel and propeller pattern and core box	15.000
25 lb. propeller and mandrel castings @ 0.15	3.750
Ball bearings, key bolts, screws, gaskets and misc.	18.000
Overhead 200% labor	45.600
Total welded pump cost	\$193.925

COST—CAST IRON CONSTRUCTION

12-inch single stage belted head, deep well turbine pump with 20-ft. of 6-inch O.D. column, shaft, bearings and oil tube.

Patterns and core boxes for complete cast pump	\$512.000
1000 lbs. castings @ 0.15 per lb.	150.000

20-ft. 6" O.D. column shaft and bearings and oil tube	40.000
40 hrs. machining @ 0.80	32.000
Ball bearings, keys, bolts, screws, gaskets and misc.	18.000
Overhead 200% labor	64.000
Total cast iron pump cost	$816.000

Comparison of Costs for One Pump:—

Cost of complete cast iron pump	$816.000
Cost of complete welded pump	193.925
Saving by welded pump	$622.075

Approximate percent saving by welded pump $\frac{816.000—193.925}{816.00} = 76.3\%$

This saving is possible where a special design is required and when the one pump must stand the entire cost of the patterns and core boxes.

When a large number of pumps are to be cast from the same patterns, it is possible to reduce the cost of the cast iron pump considerably. However, even then, as will be seen in the following example, the welded pump will make a substantial saving.

Comparison of Costs for Number of Pumps.—(Assume life of patterns good for 1000 castings)

Pattern and core box charge for complete pump	$000.512
1000 lbs. castings @ 0.15 per lb.	150.000
20 ft. of 6" O.D. column shaft, bearings, and oil tube	40.000
40 hrs. machining @ $0.80	32.000
Ball bearings, keys, screws, bolts, gaskets, and misc.	18.000
Overhead 200% of machining cost	64.000
Total cost of cast iron pump	$304.512
Cost of welded pump	193.075
Saving by welded pump	$111.437

Approximate percent saving by welded pump $\frac{304.512—193.075}{304.512} = 37\frac{1}{2}\%$

The gross saving to the pump industry is not known and would be difficult to estimate but since this industry is large, a considerable saving should be made.

Description of Parts of Welded Pump.—(Beginning at top of Pump)—BELTED HEAD: Consists of a vertical pulley, mandrel, spacer, ball thrust and radial bearings, bearing housing, bearing plate, support cone, base plate, sight feed oiler, sight feed oiler standard, oil tube and pipe cover, oil tube tension nut, washer and gasket, oil tube cap, shaft nut and key, together with necessary bolts, nuts, and screws to make a complete assembly. Fig. 2 shows complete detailed construction.

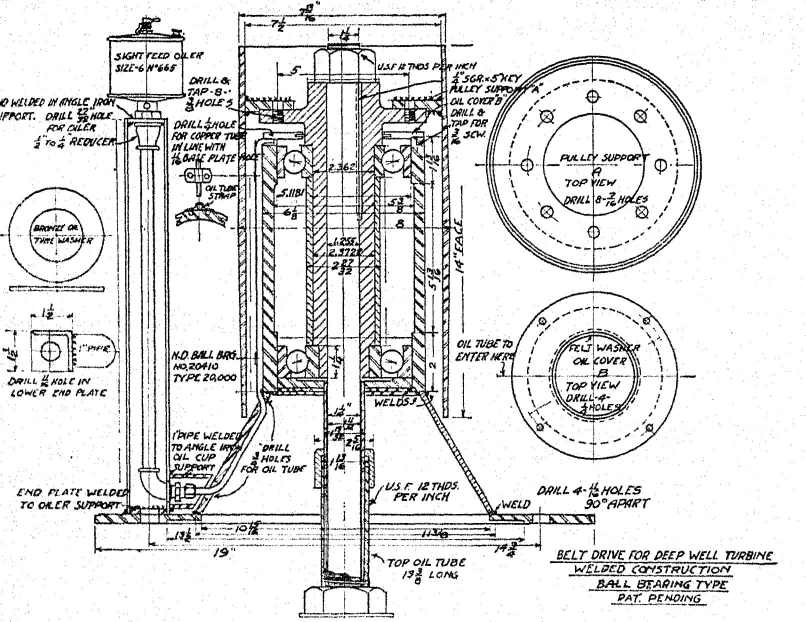

Fig. 2. Detailed construction of arc welded pump.

Note: Where direct motor drive is desired, the belted head need not be used as standard vertical motors are available and will fit top of discharge head.

DISCHARGE HEAD: Consists of head plate, shell, convex head, base plate, discharge nozzle and flange.

COLUMN: Consists of outer column and inner column or oil tube, shafting, bearings and couplings. Each column is 10 ft. long, having a supporting bronze bearing every five feet. The bearings are threaded on the outside and serve as couplings for the oil tube or inner column.

The flanges on the outer column are so constructed as to make a male and female joint, insuring tightness and perfect alignment.

The water passage is between the inner and outer column. The column sizes will vary in accordance with the pump sizes and the horse power required for driving.

TOP DIFFUSOR: Consists of a flange, diffusor nozzle, outer cone, inner cone, propellor plate, propellor ring, bottom flange, bearing tube, diffusor vanes, relief port, bronze bushing, spacer, top diffusor bearing of bronze, shaft, key, propellor, and propellor nut. Fig. 3 shows pump diffusor.

INTERMEDIATE DIFFUSOR: Consists of top plate, nozzle, inner and outer cone, diffusor vanes, propellor plate, propellor ring, bottom flange, bearing and spacer tube, spacer bushing, propellor and key, and

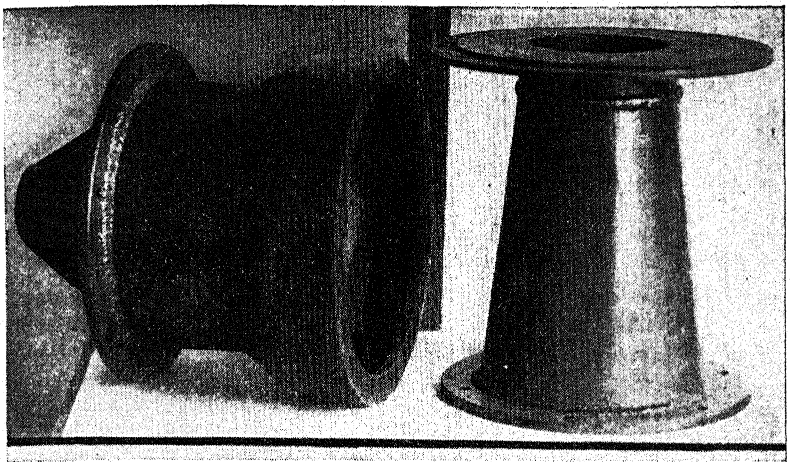

Fig. 3. Welded pump diffusor.

propellor nut. Where an intermediate diffusor is used, use special length propellor shaft.

SUCTION CASE: Consists of top flange, nozzle, cone, tail bearing tube, tail bearing bushing, guide vanes, tail bearing plug, together with necessary bolts and screws to make complete assembly.

TEST DATA ON 12-INCH WELDED DEEP WELL TURBINE

Head in Ft. Gage	Static Head in ft.	Friction Head in ft.	Velocity Head in ft.	Total Head in ft.	Weir Reading in inches	G.P.M.	B.H.P.
31	7	0.0	0.0	38.00	0.0	0	2.0
25	7	.80	.24	35.54	2	200	6.0
20	7	1.69	.52	33.21	3 3/16	400	7.0
15	7	2.46	.76	30.52	4 3/16	596	7.5
10	7	5.40	1.51	27.50	5⅛	800	8.5
5	7	7.64	3.04	21.68	6	1000	9.0
0	7	8.30	3.43	18.73	6 3/16	1050	8.85

Note: The above test was made with a standard 2-ft. contracted weir.

The deep well turbine pump requires no foot valve since it is self-priming because the impellor is submerged below the water surface at all times.

The entire thrust load of water plus the weight of all rotating parts is carried by the thrust bearing in the belted head, or by the motor thrust bearing where a vertical motor is used.

All joints are rabbet fit so that perfect alignment is insured, resulting in perfect vibrationless operation.

Materials Used for 12-Inch Deep Well Turbine Pump.—In the construction, the following materials were used:

(a) Mild steel plate
(b) Standard and extra heavy Shelby tubing
(c) Coated welding rods
(d) Cumberland ground steel shafting
(e) Tobin bronze bushings and bearings
(f) New Departure ball bearings
(g) Standard 6-inch O.D. casing for outer column

The arc welded parts of the pump are shown in Fig. 4.

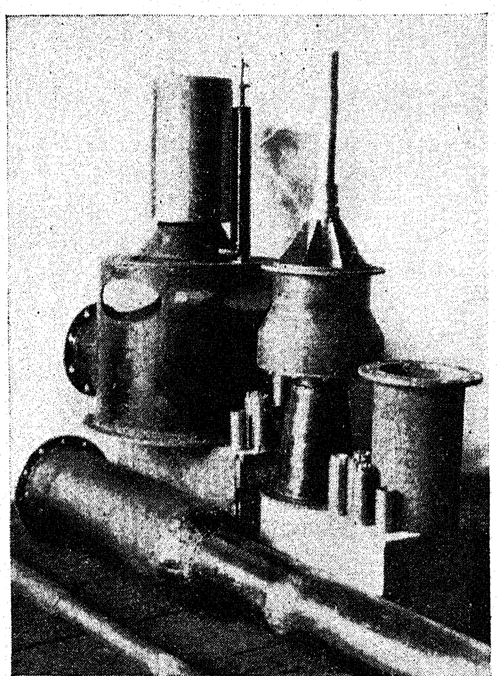

Fig. 4. Welded 12-inch deep-well turbine pump.

Conclusions.—1. That the welded pump is cheaper to build than the cast iron pump and has the added advantage of being applicable to special design to meet special conditions.

2. That further saving can be made for the welded pump by using stampings or formed parts in construction of its parts where a large number of units of similar sizes are to be made. This also tends to increase the efficiency of welded pump.

3. The welded pump has a decided advantage over the cast iron pump due to its greater strength and larger capacity for a given size, made possible by the thinner wall sections of the welded pump. This allows for larger water passage and therefore larger capacities.

4. The welded pump makes possible the use of special alloys such as stainless steel, etc., which are difficult or impossible to cast.

5. The welded pump would reduce the cost of special alloys in its construction, due to the thinner cross section of the metal used.

6. Because of the uniformity and strength of steel plate, the welded pump would have greater strength than the cast iron pump and would be applicable to deeper settings and higher pumping heads than is possible with the cast iron unit.

7. The danger of breakage would be eliminated by the welded pump construction. This would also greatly add to the ease of installation due to its lighter weight.

8. The welded pump will have a longer life than is possible with the cast iron pump because of the feasibility of using special alloys in its construction to counteract corrosive or abrasive action of liquids being pumped.

Chapter XIV—Arc Welding in Business Machinery

By L. F. MITCHELL, F. E. CURTIS and C. J. HUEBER,
Chief engineer, and engineers, respectively, Addressograph-Multigraph Corp., Euclid, Ohio.

The "Addressograph" is the office machine that has taken the drudgery out of routine copying of names, addresses and other short data, such as involved in insurance, tax, social security, payroll, public utilities, and other recordings too numerable to mention.

As the name implies, the "Addressograph" was originally intended to reproduce addresses. This imprinting consisted of three, four, and five lines.

MR. JOHN JOSEPH DOE
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DOE CITY
U.S.A.

The original machine was a simple mechanism for printing from a series of rubber stamps mounted on an endless chain. Remarkable has been the progress. The present machine prints from an embossed metal plate through a ribbon.

In its present position in business, addressing is a minor function of the machine—the major portion of the imprinting being done from metal plates that contain up to ten lines of embossed type.

The data contained on the plates is frequently imprinted in several columns and oftentimes on long or continuous forms.

When four or five line imprints were the maximum requirement, a reciprocating imprinting arm made of cast iron, with a flat rubber platen, was satisfactory (See Fig. 1).

With extensive changes in business and other users' records, the required lines of imprints increased and the flat platen was replaced with a rubber roller platen because of the better imprint possible with a rubber roller platen on the increased number of lines. (See Fig. 2).

With use of the roller platen, it became necessary to add a pressure block to the reciprocating arm, commonly called stamper arm, in order to properly position the arm to provide the right distance for uniform imprinting and proper rigidity in the arm. This block is merely a small piece of steel attached securely to the stamper arm, contacting the top of the machine on each downward stroke of the arm. The purpose of this pressure block was not only to act as a distance gauge between the bed and arm, but it pre-strained the arm to a pressure greater than the imprinting pressure.

The amount of strain that this device applied to the main bed and stamper arm of the machine can be readily appreciated but because of its essential function, it could not be eliminated.

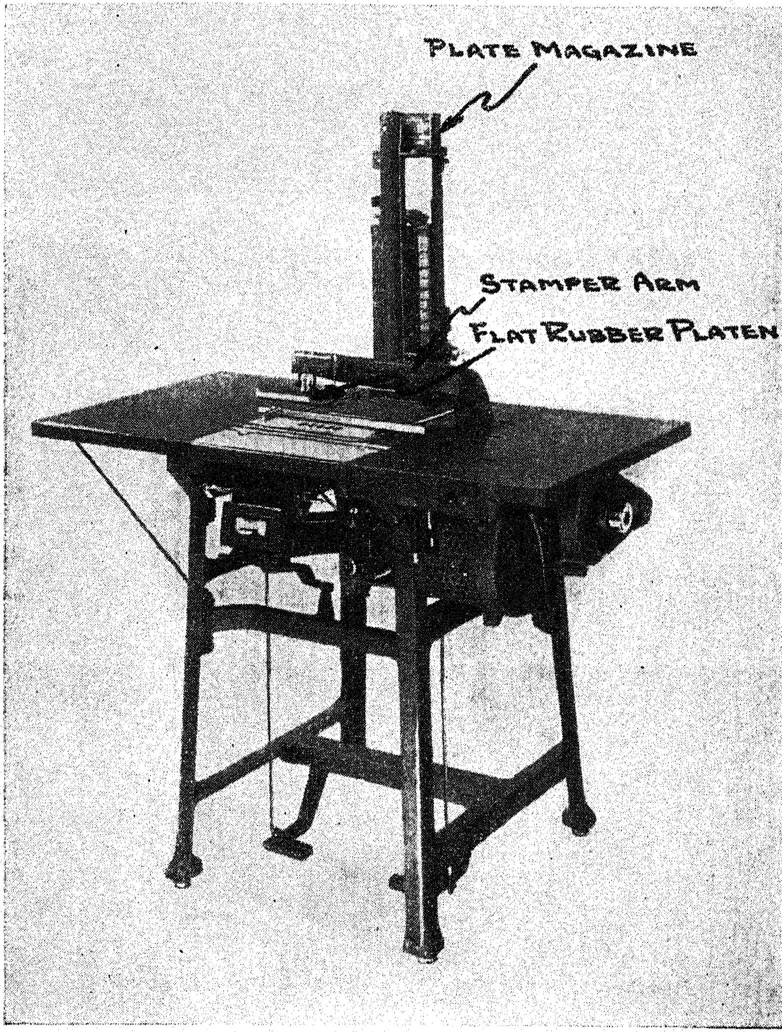


Fig. 1. Addressing machine of cast iron construction.

The adoption of the roller platen introduced problems as to rigidity of other component parts in the printing unit. Without rigidity in the printing members, it is impossible to produce uniform imprints. Since adoption of the roller style platen, years of engineering have been devoted to the problem of rigidity and strength.

Revolutionary New Addressograph Because of Arc Welding.—Ever increasing complexities of applications to be handled made it apparent that increased marginal possibilities would have to be provided. It was

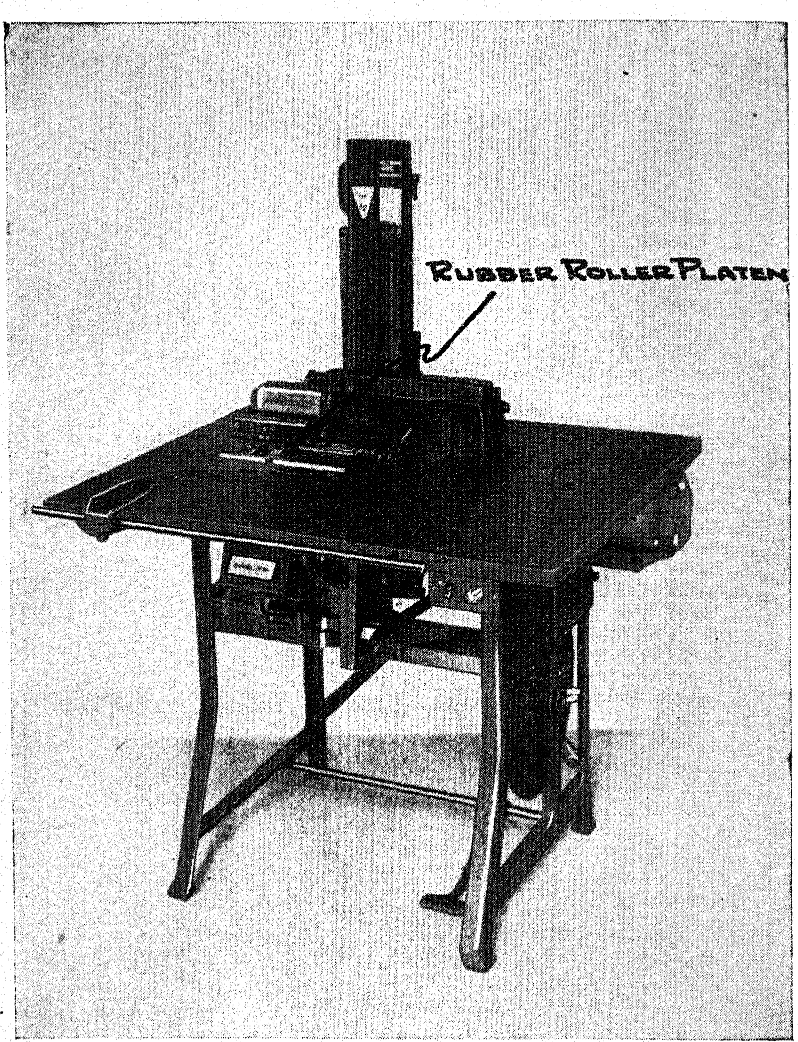


Fig. 2. Cast iron addressing machine having rubber roller platen in place of flat platen on machine in Fig. 1.

evident that limitations on the present machine would have to be refined, and an even more versatile machine developed, eliminating the pressure block.

Therefore, after a great deal of study, designs were conceived locating the base of the printing arm and plate magazine in the right rear corner, the plate magazine being that portion in which the plates are placed preparatory to imprinting. This new location of these units refined former limitations and permitted imprinting forms that were heretofore too large or too complicated to be handled. Simultaneously, tests proved

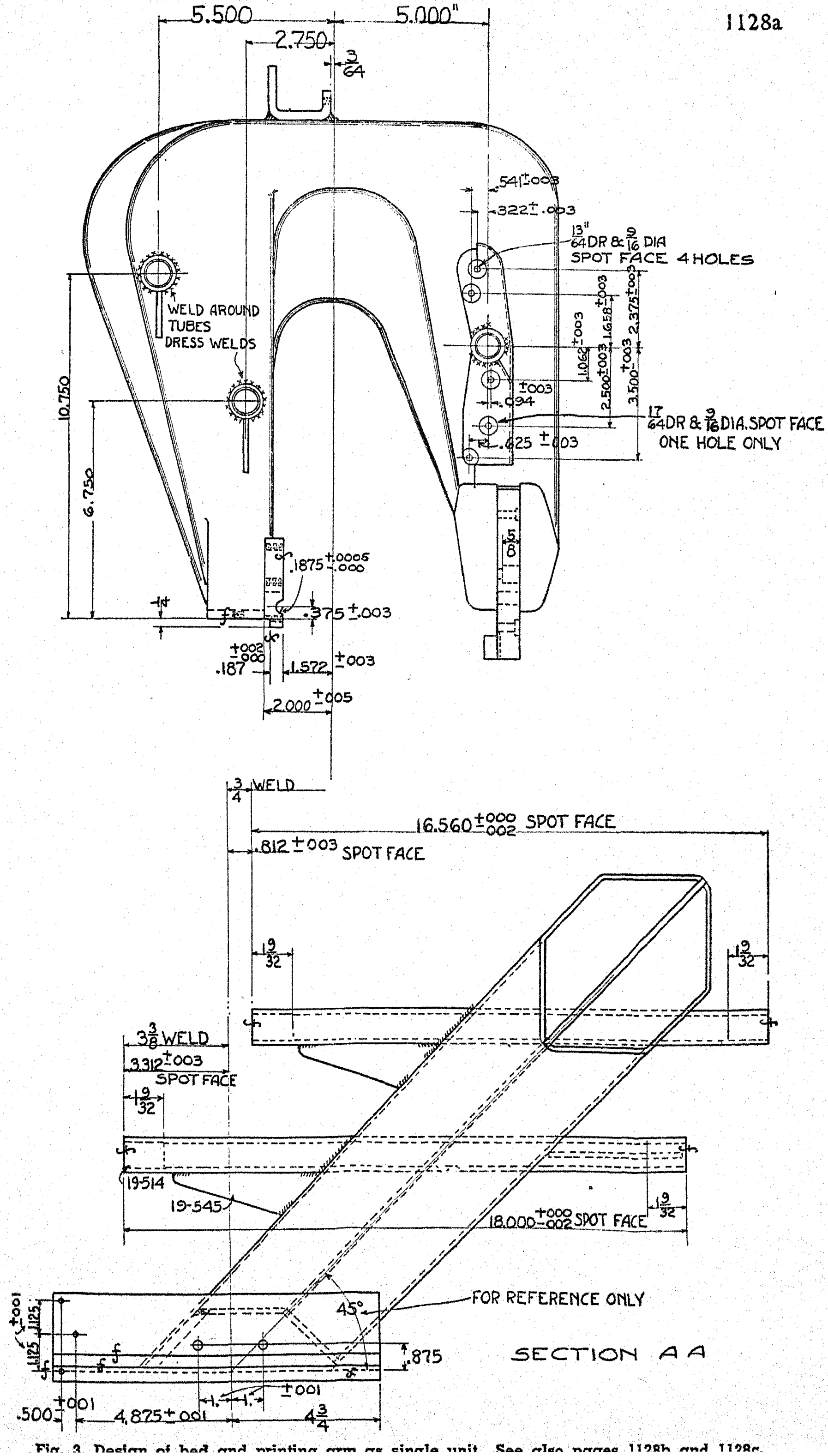


Fig. 3. Design of bed and printing arm as single unit. See also pages 1128b and 1128c.

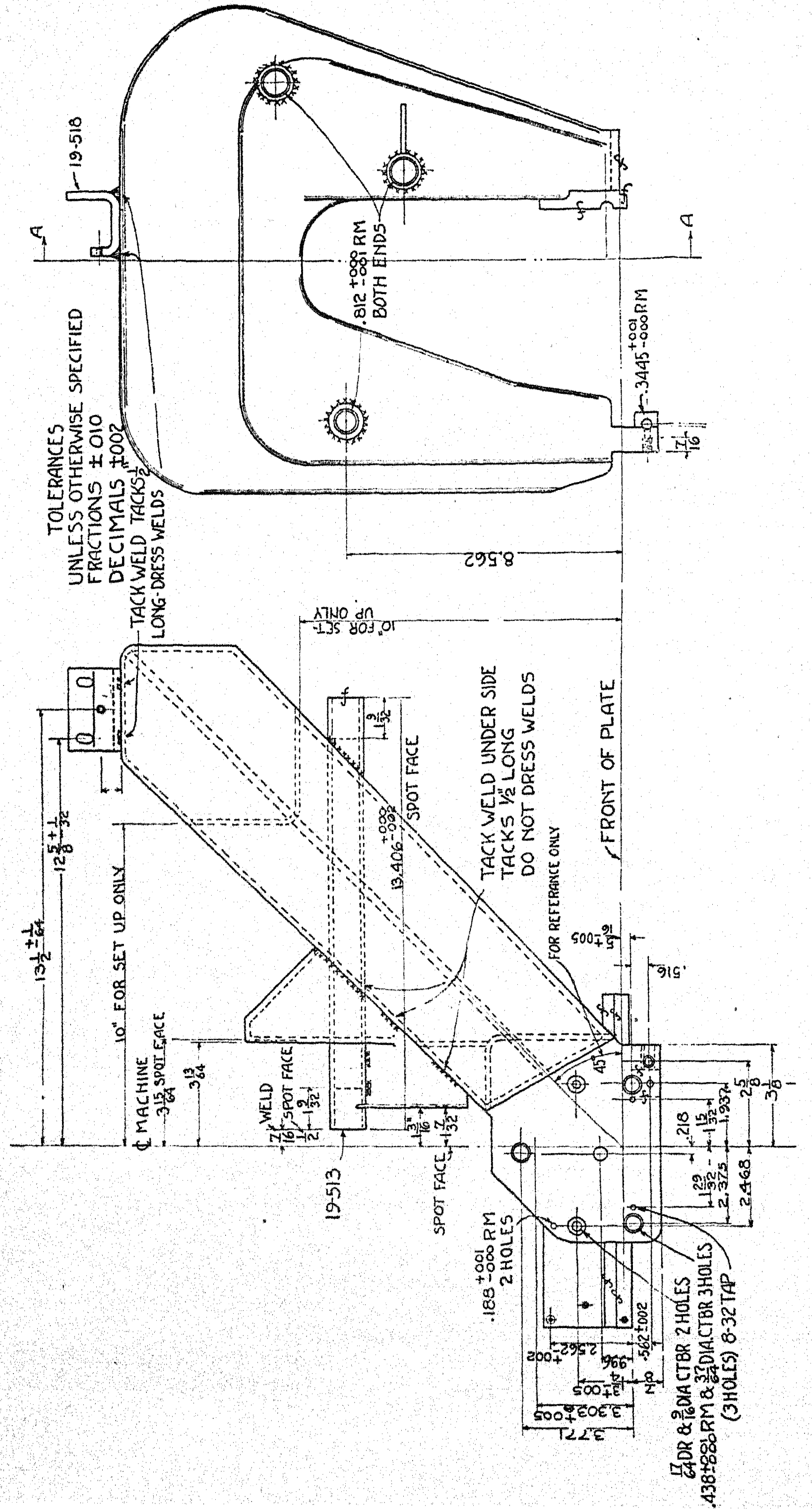


Fig. 3. Design of bed and printing arm as single unit. See also pages 1128a and 1128c.

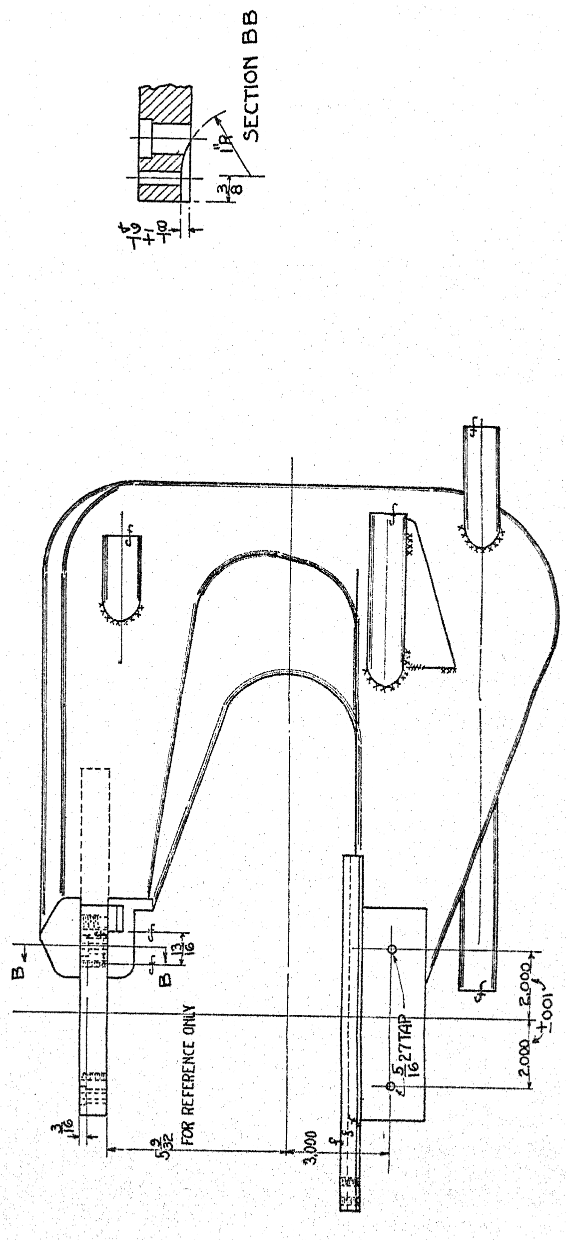


Fig. 3. Design of bed and printing arm as single unit. See also pages 1128a and 1128b.

that a rigidly fixed printing arm would provide more satisfactory imprints than the former reciprocating arm, and it was decided to embody this type arm in this model. One of the advantageous features of a fixed arm would be the elimination of the necessity for use of the pressure block.

This was the beginning of a new era in the addressing machine field, and at the same time, problems were presented in constructing a printing arm in which a minimum amount of deflection would be present when imprinting, and an arm which would be manufactured at lowest cost.

With removal of the printing arm and plate magazine to a more remote position on the machine, it was necessary to completely alter the mechanism through which the plates move, and it became necessary to add considerable material to these units. Heretofore, the bed, or main unit, of the plate movement mechanism on all former automatic machines weighed approximately 50 pounds, and made of cast iron in the new structure these units weighed 90 pounds. It was apparent that this difference in weight would not only greatly increase the weight of the machine, but the cost would be excessive.

Innumerable experiments were conducted with a cast iron printing arm rigidly bolted to a cast iron main bed in our endeavor to obtain rigidity in these parts, the combined weight being 170 pounds, but even with this abnormal weight there was too much deflection present to permit uniform imprinting.

The office appliance industry has developed machines to a high degree of perfection through use of cast iron as a base metal, but disheartening were the results of tests of this construction in this machine as a deflection of .020″ was present, and it was feared that it may be necessary to return to the pressure block construction of former models. The pressure block was one of the most serious objections because of the strain imposed on operating parts, and, in addition, it frequently smudged the copy being imprinted, particularly while listing on long sheets containing carbon paper.

Having heard of the remarkable possibilities of arc welded construction, the sales engineers of a well known arc welding equipment manufacturer were consulted and they were enthusiastic concerning the applicability of this advanced method of fabrication to our new product.

The machine in which this construction is being used is now being engineered and is not quite ready for production, but arc welded construction has proven to be the answer to one of the most difficult problems that has ever confronted us.

Through use of arc welded steel construction it is possible to make the bed and printing arm of the "Addressograph" in one unit (See Fig. 3). In thorough tests of this construction, it has been proven that there is no deflection present in the imprinting units when an impression is being made. Furthermore, with arc welded construction the weight of the bed and printing arm is reduced from 170 pounds to 70 pounds.

What is remarkable about this construction is the fact that it will not only provide a reduction in weight and cost, but for the first time in the addressing machine field it will be possible to construct a bed and printing arm in one unit and one in which there will be no deflection present, even with the absence of a pressure block.

We are pioneering in arc welded construction in the business machinery industry and believe that its possibilities are unlimited in our line. We can see a multitude of applications where arc welding can be advantageously used in our products.

Proportionate Cost Saving.—The arc welded bed and printing arm unit in the revolutionary new "Addressograph" will result in a proportionate cost saving of 31.86%.

Considerable saving will be involved, not only in material, but also in machining labor. For instance, the original cast iron construction of a separate arm and bed cost $16.93 for raw material, whereas the complete cost of fabricating and welding the combination steel bed and arm is $4.27. The cost of machining the two cast iron units was $11.85 and the cost of machining the arc welded one-piece construction is $4.90.

However, the foregoing saving is not the only saving involved. Use of the one-piece construction will simplify the manufacture of the entire machine and therefore reduce costs throughout.

Gross Savings Accrued Through Use of Arc Welded Construction.—An enormous saving will be made in the new construction, not only because of the less expensive equipment required, but also because of the welded construction of the combination bed and printing arm making it possible for us to work out more simple and economical plate movement mechanisms, eliminating much of our former milling work, and in substitution, using special rolled sections. Where we are now building most of the machine from cast iron, we will practically entirely eliminate the use of this metal and use arc welded steel, special rolled steel, die castings, and plastic materials.

Our gross savings accrued through use of arc welded construction in the bed and printing arm will be as follows:

Former Construction	
Tools and Patterns	$14,340.00
New Construction	
Welding Equipment and Fixtures	$ 7,650.00
GROSS SAVINGS	$ 6,690.00

Increased Service Life Efficiency and Economy.—Through use of a combination one-piece bed and printing arm, instead of two cast iron members bolted together, the service life of the machine will be lengthened to an indefinite period. Tests have assured us that this will be a permanent construction, and will be extremely more efficient than previous designs and will be trouble-proof.

Because of the arc welded construction, the user of this machine is assured of uniform strength in parts, and against any flaws that would be present in other methods of fabrication.

The revolutionary new machine will be more desirable from an operative standpoint because of the simplified construction and minimized adjustments made possible through the unit construction of the major operating parts.

Coordination in Design Possible Because of Arc Welded Construction.—Coordination in the design of the machine is possible because of the simplicity of construction provided by the arc welded method. Through this construction, the new machine will more closely resemble an office fixture than a factory machine. An arc welded steel stand is also being used in this machine and is extremely attractive in appearance.

Compactness in the design of the new machine is possible through arc welded construction as tolerances can be very close, whereas in other methods of manufacture it is necessary to provide for greater variations in parts.

The beauty of the revolutionary new arc welded machine can be appreciated by comparing old models with new ones. Former machines have been more massive and ungainly appearing because of the weight necessary in order to obtain strength in the materials formerly used.

Chapter XV—Hydraulic Manifold Designed for Arc Welding

By HERBERT A. SILVEN,
Machine designer, Norton Co., Worcester, Mass.

This subject manifold is not limited to one type of machine, but can be applied to great advantage to any type of a hydraulically operated machine, having a multiplicity of pipe lines.

The reduced cost of manufacture and simplicity of assembling are only some of the advantages realized. Other advantages which can be realized are:—reduction in service calls and expenses of field representatives in response to complaints of faulty and leaky connections, especially where vibration exists.

Flared tube connections cannot withstand the constant pounding exerted upon them by the rapid movements of massive machine units, without peening or compressing at the flare, and causing a loose connection. In some cases these connections are difficult to get at and require considerable disassembling of machine parts in order to tighten. All this increases the down time of the machine, reduces its efficiency and leaves the customer with a bad taste, and very little patience for the machine.

On a machine having a number of hydraulic movements there will always be an abundance of tubes, pipes, and fittings. The proper location of these connections is always more or less difficult for a shop mechanic to grasp, especially when he is following an assembly drawing, which, in the first place is difficult to make and convey very clearly the exact locations, as one or more pipe lines invariably run together and are difficult to follow through. This confusion always requires a good deal of supervision and explaining from an engineer who is acquainted with the machine.

An assembled manifold that can be assembled into the base of a machine without any danger of improper location, will not only simplify the assembly but will eliminate to a large extent the time usually spent by an engineer or foreman to supervise the work. An error, due to a wrong connection, can very readily be the cause of a costly accident to both operator and machine.

Such manifolds are economical and simple for permanent assembly into machine bases having close quarters, and assure a rigid and leak proof unit, most especially where complicated pipe lines are necessary. It may be subjected to varying degrees of temperature and severe mechanical strains and assure accurate performance. The secure manner in which the joints are fused together will add greatly to the life of any machine, and reduce maintenance costs to a minimum.

Welded joints will eliminate oil leakage, which is a matter of great importance and cannot be overlooked, without emphasizing some of the evils connected with this matter. Any leak, no matter how small, will, to a certain degree, depending upon amount of leak, reduce the efficiency of the machine functions; not only in loss of pressure, which will retard

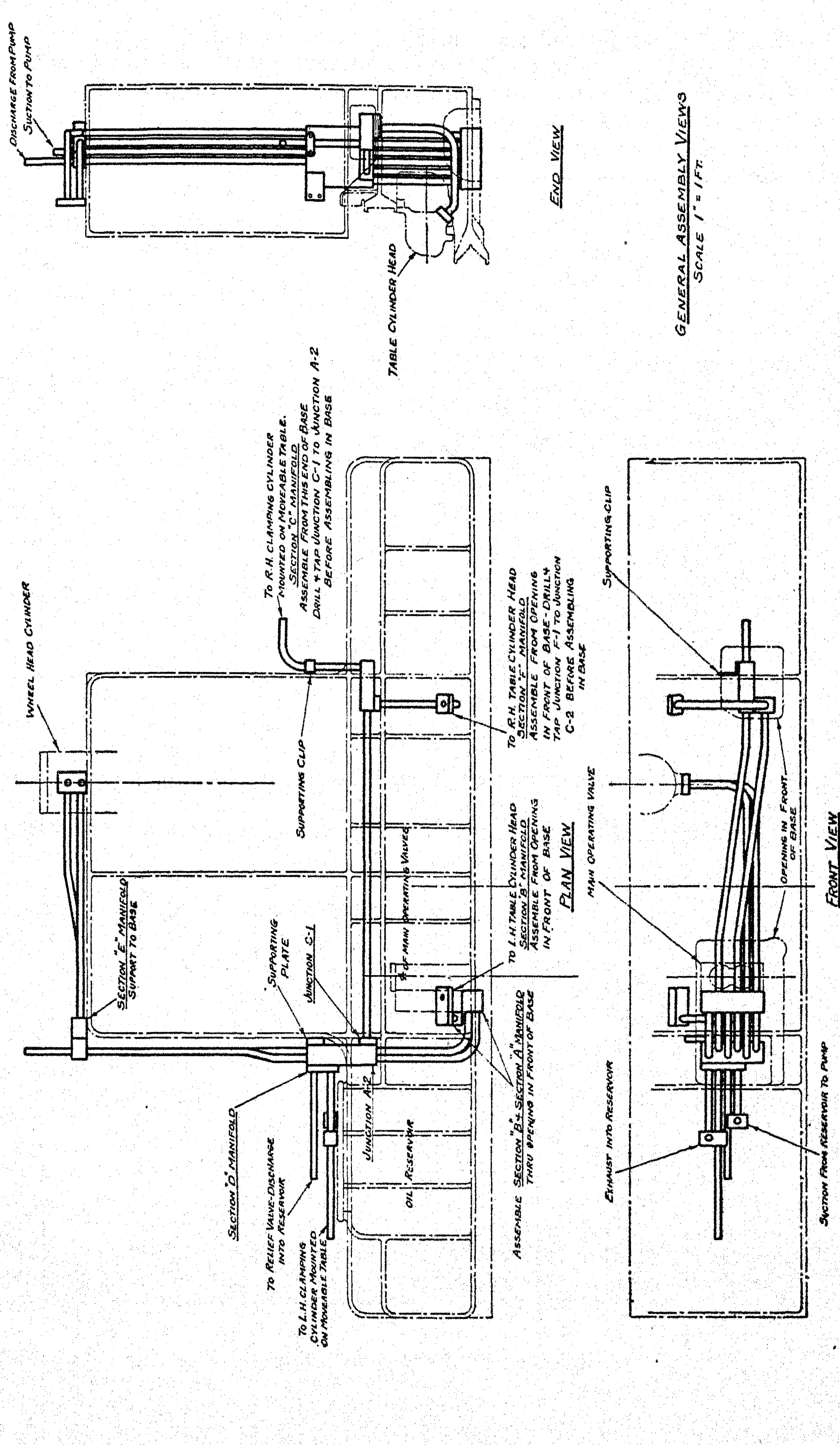


Fig. 1. General assembly views showing connections of manifolds to each other and assembly to base.

the functions, but will also afford an entrance for air. The presence of air pockets, in any hydraulic motor unit that is used for accurate indexing or sensitive feeding movements, is generally the cause of spoiled work or costly repairs. The air is sucked into system through leak and is trapped at the highest point, which, when subjected to pressure, will yield and cause an indefinite movement of machine function. If a uniform slow feed is required, the presence of an air pocket will cause an intermittent motion, without any definite or positive movement. Usually a good deal of time is spent in locating the exact position of the leak which is causing the trouble.

Oil leaks are also a source of danger if oil is allowed to run onto the floor and may cause physical injury to shop men. Practically all automotive shops employ men whose sole duty it is to mop up oil on the floor, sprinkle sawdust around the base of leaking machines and sweep up the sawdust at regular intervals during the day. Oil consumption is also a factor of economy to be considered, when leaks are prevalent. The type of oil recommended for hydraulic machines is generally a light oil, which will run freely in normal temperatures.

A majority of the modern shops of today take a great deal of pride in the cleanliness and appearance of their various departments. As a matter of fact, one of the largest automotive plants has a system of interdepartmental competition, awarding a merit of appreciation for the most orderly looking department, every month, and it is considered a distinction by everyone connected with that department. This creates a demand for hydraulically operated machines that will not drip oil onto the floor and so require the sprinkling of sawdust to absorb the oil.

The conventional piping or tubing construction will require a number of various fittings to be carried in stores, otherwise serious delay may be encountered, if depending on deliveries from all over the country. Assembling of machine will be delayed until fittings are received. Rush orders for items such as these are usually sent in the form of a costly telegram or telephone conversation, with instructions to ship as soon as possible; involving an added expense.

The subject design will not require this investment of storing fittings, but can be scheduled and produced from standard bar stock as quantity demands, without any unnecessary and costly delay.

Each individual tubing used on conventional design must be cut to proper length, and flared with a special tool, when assembling. If pipe is used, it must be cut to length and threaded. Extreme caution must be used in order to obtain a very accurate alignment of tube with fitting, so that when entering the threaded nut, the threads will not become cross threaded, and ruin the connection. This is also true with ordinary pipe which will require the use of some suitable sealer for an oil tight connection. This sealing compound usually becomes emulsified with the oil used in the hydraulic system, and will very readily cause a sticky operating valve to function improperly or not at all. The sliding tolerance of a piston inside of a balanced piston valve is usually .0007″ to .001″ smaller than honed hole inside of valve sleeve, which will not permit the use of any sticky or gummy substance in the oil, in order to function satisfactorily.

The subject design will not require the use of any sealer compound,

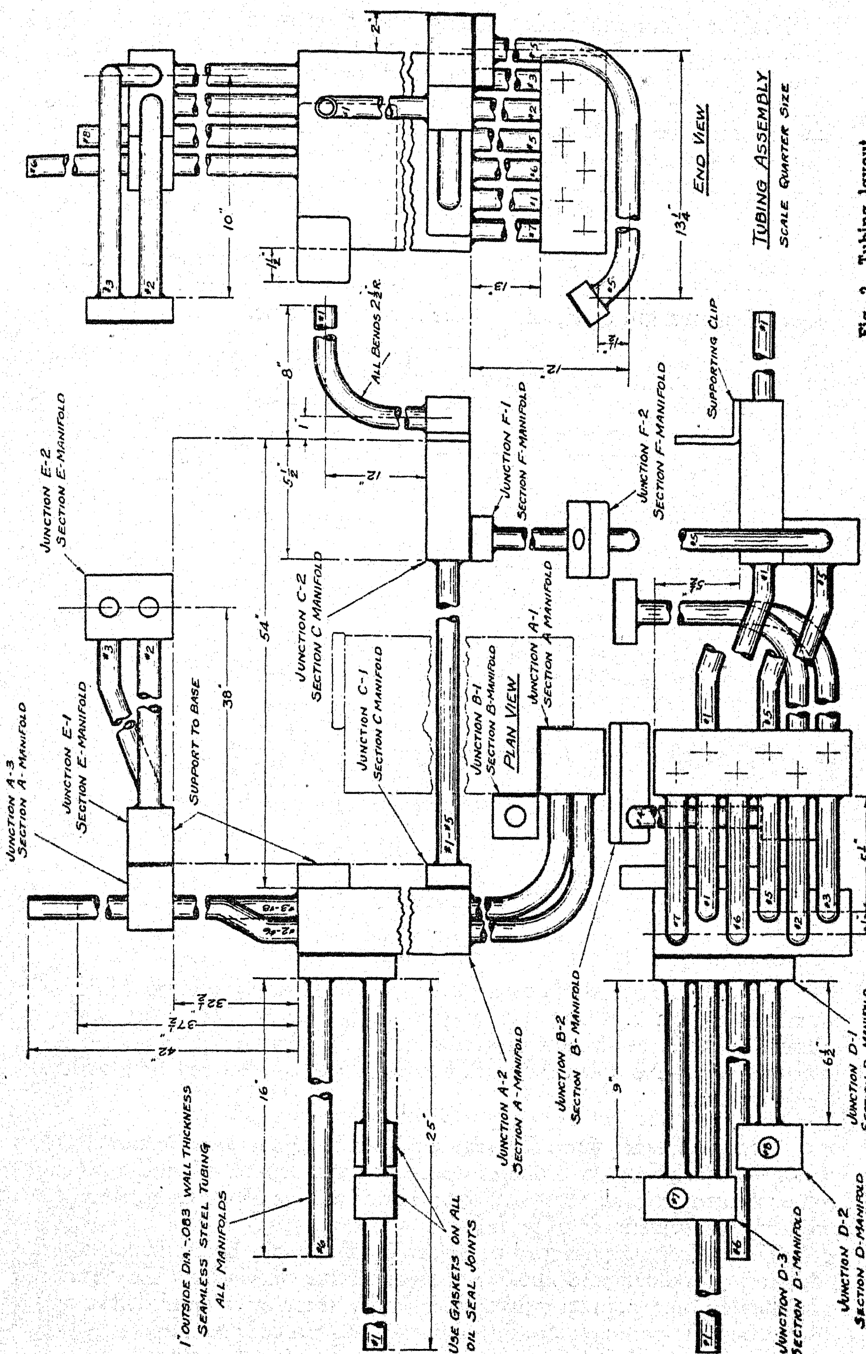


Fig. 2. Tubing layout.

and hence eliminates faulty sliding fits of operating valves. Cutting tubes and pipes to length, flaring and threading are entirely eliminated at assembly, making a much more simplified construction at less cost.

In most hydraulic machines a big proportion of the pipe lines and fittings must be inside the machine base proper, in order to connect to various valves and hydraulic units which are attached to base. This necessitates providing ample space inside of base to swing large wrenches and in order to furnish this space it will tend to weaken the base structure.

The subject design will not require the use of large wrenches used for pipe or tube fittings, and will permit the assembly inside of base, without sacrificing strength or rigidity in the base of machine.

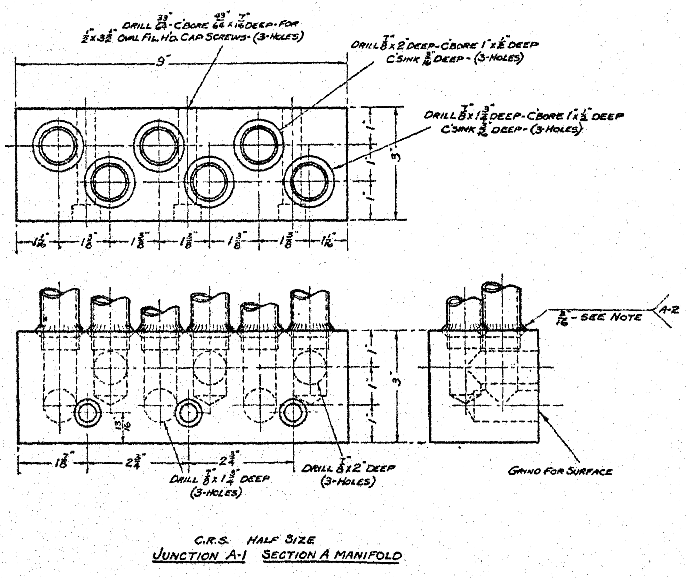


Fig. 3. Detail Junction A-1.

All of these items add to the savings, which industry in general may realize through the adoption of the subject design. It is difficult to visualize the great amount of savings that can be attained through these sources alone. No doubt they will vary in proportion with each individual manufacturer.

General Description of Hydraulic Machine Functions Pertaining to Subject Machine.—In order to appreciate the conditions under which the subject manifolds must perform, a brief outline of the essential rapid machine movements is offered.

The machine is designed to grind all of the pin bearings and their adjoining shoulders and fillets on an automotive crankshaft. The rate of production on a popular priced six cylinder automotive crankshaft averages 10 shafts per hour, or approximately one pin bearing a minute. The hydraulic pressure pump supplied for this machine is a low pressure

pump having a capacity of 36 gallons per minute at a pressure of 75 to 80 pounds per square inch.

The wheel slide, carrying the grinding wheel is traversed to and away from the work, once every minute, by hydraulic pressure, at the rate of 30 feet per minute and weighs about 3400 pounds. The sliding table supporting the work heads is traversed hydraulically from one pin bearing to another longitudinally, once every minute, at the rate of 40 feet per minute, and weighs 3500 pounds.

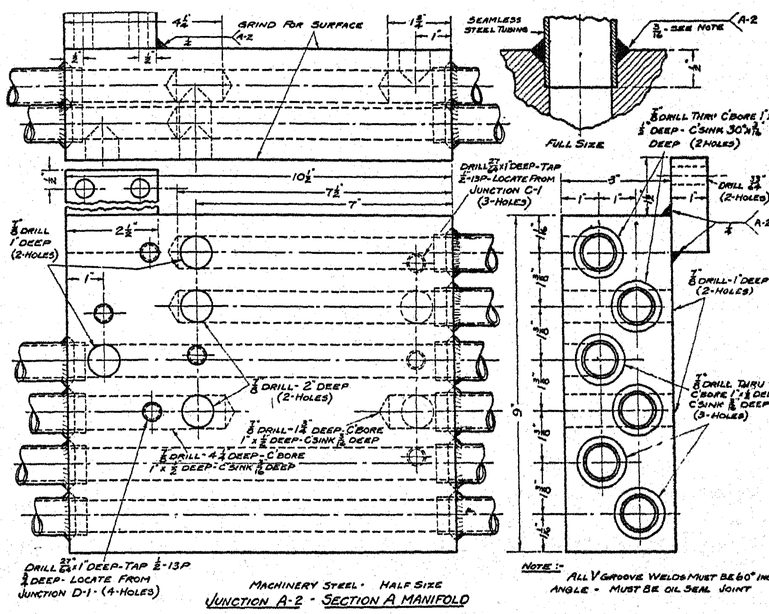


Fig. 4. Detail Junction A-2.

When dressing the wheel, which must be done after grinding every three or four shafts, a dresser tool is mounted in place of the work, and sliding table is moved, so that dresser is traversed rapidly back and forth across the face of grinding wheel, for approximately one-half to one full minute. The work holder clamps are operated once every two minutes, but has no mass to move.

The steadyrest is raised and lowered by hydraulic pressure, once every minute at a fast rate of speed, and weighs approximately 150 pounds. No manifold for this unit is shown on subject design and necessary tubes and fittings are not included in original cost for the purpose of comparison. The steadyrest unit must be mounted to machine base so that a lateral movement can be obtained for wheel alignment, and will be furnished on all future machines with flexible pipe lines.

All of these rapid hydraulic movements especially the massive wheel head and sliding table, set up vibrations and a continual pounding within the tubes carrying the pressure.

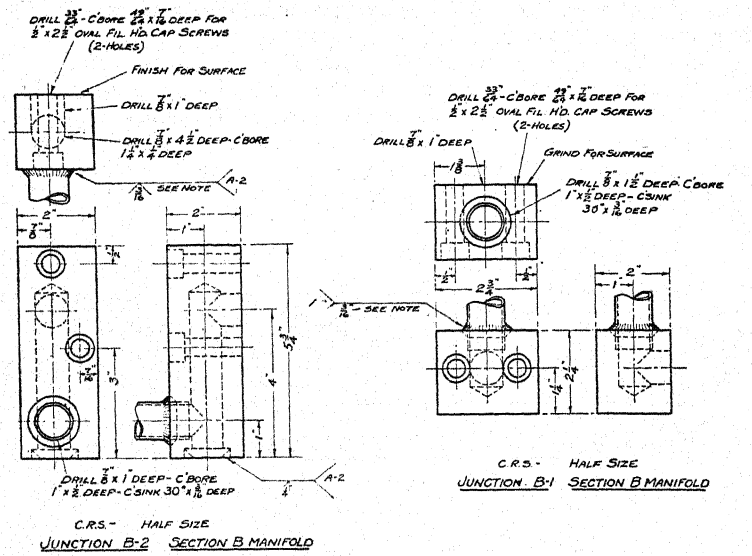


Fig. 5. Details junctions B-1 and B-2.

Method of Manufacture and Assembly of Subject Manifolds.—All junctions and manifold supports are made from stock size cold rolled steel or machinery steel bar stock, routed through the shop in the usual manner for all necessary machining, and finally to the welding department.

The tubing used is seamless steel tubing 1″ outside diameter having .083″ wall thickness. These are cut to length and shaped if required, in the welding department, and tubes and junctions are then prepared for welding. The tubes are supported in place on the junctions by a snug fit in counterbored holes, allowing a horizontal weld to be performed. All tube joints to be 60° included angle, by $\frac{3}{16}$ deep V type welds.

The supporting plate on junction A-2, (See Fig. 1), will be joined by two ¼ fillet type welds, and the plug-in junction B-2, (See Fig. 2), by a bevel type weld. The tube joints must be leak-proof and remain smooth on the inside to lessen the frictional resistance of the flowing oil, in order to keep the oil temperature down to a minimum.

After inspection the sectional manifolds are routed to the assembling department, where they are fitted in place and joined together.

The tubes can be bent slightly if necessary to line up with adjoining junctions or conform with the base outline, when assembling. (See Fig. 2).

In order to assemble the manifold inside the machine base, it is made up of six sectional manifolds, which are joined together through junctions and gaskets. Gaskets will be used at all joints requiring a seal, made from some suitable material, such as Vellumoid. The support shown on junction C-2, Fig. 2, is made adjustable for proper positioning to compensate for any variation in base length. This is preferable to eliminate any welding on assembly floor.

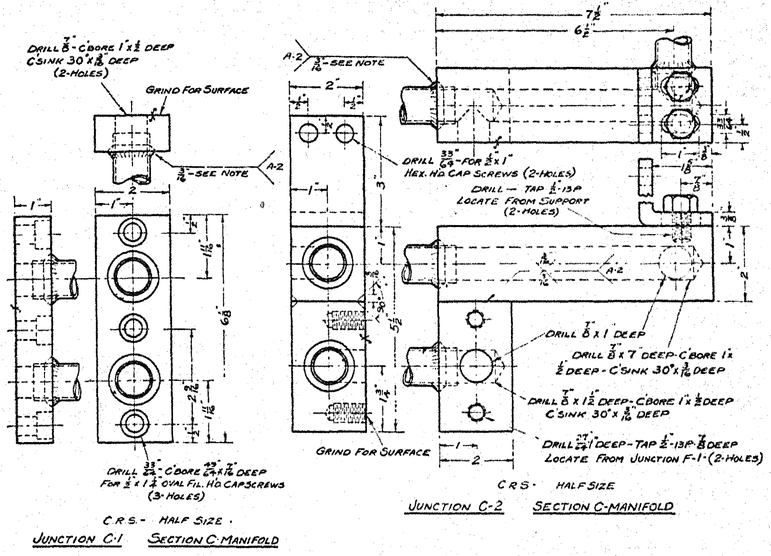


Fig. 6. Details junctions C-1 and C-2.

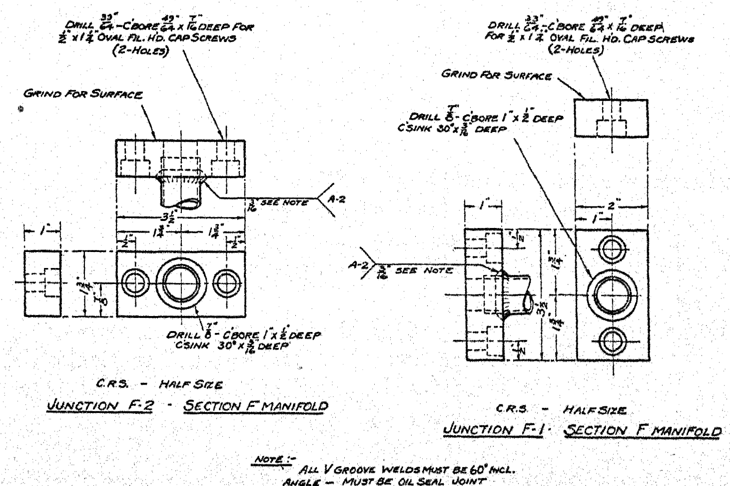


Fig. 7. Details junctions F-1 and F-2.

Before assembling sections into machine base, holes are drilled and tapped into junction A-2, locating from junction C-1, also into junction A-3, locating from junction E-1; also into junction C-2, locating from junction F-1. All other joints can be fastened and located at assembly.

Section A manifold will be assembled through opening in front of base and fastened to main operating valve by three ½″ screws in junction A-1, (See Fig. 3), and fastened to outer wall of base, by two ½″ screws in support on junction A-2, (See Fig. 4).

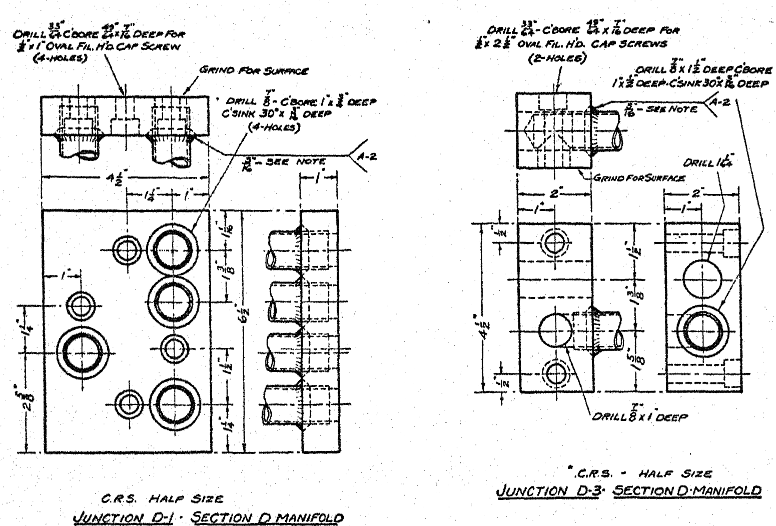


Fig. 8. Details junctions D-1 and D-3.

Section B manifold, (See Fig. 5), will also be assembled through the same opening in front of base, previous to assembly of Section A and fastened to main operating valve by two ½″ screws and two ½″ screws in left hand cylinder head.

Section C manifold, (See Fig. 6), is then assembled through opening in base from the right hand end, and fastened to junction A-2 on left hand end by three ½″ screws, and to the base on right hand end by two ½″ screws.

Section F manifold, (See Fig. 7), is assembled through opening in front of base and fastened to junction C-2 by two ½″ screws and to the right hand cylinder head by two ½″ screws.

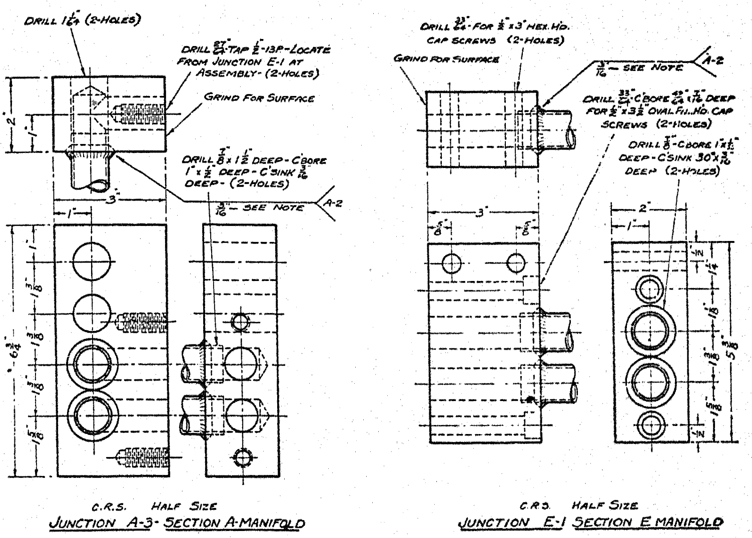


Fig. 9. Details junctions E-1 and A-3.

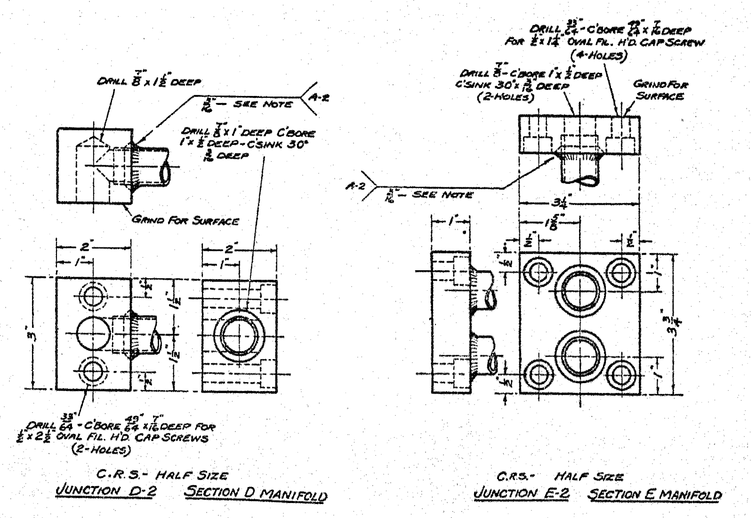


Fig. 10. Details junctions D-2 and E-2.

Section D manifold, (See Fig. 8), is assembled on outside rear portion of base, fastened to junction A-2 by four ½" screws and to the machine base from junctions D-2 and D-3, by four ½" screws.

Section E manifold, (See Figs. 9 and 10), is assembled on outside rear wall of machine base by four ½" screws from junction E-1, two of which are support screws into machine base, and four ½" screws from junction E-2 into wheel head cylinder housing.

This completes the assembly in so far as the subject manifold is concerned, other work and material necessary to connect the pump, relief valve and flexible hoses are not mentioned for comparison purposes. All gaskets are cut to size and applied at assembly.

ESTIMATED DIRECT COST OF LABOR AND MATERIAL OF SUBJECT DESIGN

1" Outside Diameter—.083" wall thickness seamless steel tubing 48 feet @ .237¢ per foot	$11.38
Cut to length—2 min./cut—82 min.	2.21
20 Bending operations—6 min./bend	3.10
38 V type welds—60° x $\frac{3}{16}$" x 120"—Rate of 9 ft./hr., plus handling time 3 min./weld	3.08
2 Fillet type welds ¼" x 5"— Rate of 9 ft./hr., plus handling time 3 min./weld	.16
1 Bevel type weld $\frac{3}{16}$" x 3¼"— Rate of 9 ft./hr., plus handling time 2 min./weld	.05
11 Vellumoid Gaskets—1 sq. ft. @ $3.00/square yard	.33
Cutting and Fitting Gaskets—2 min. each—22 min.	.59
⅛" Type "M" Arc Welding Wire—6 lbs. @ 12.3¢/lb.	.74
½" x 1½" Hex. H'd Screw—2	.066
½" x 1" Oval Fil. H'd Screws (Socket Type)— 4	.260
½" x 1¼" Oval Fil. H'd Screws (Socket Type)—11	.743
½" x 2" Oval Fil. H'd Screws (Socket Type)— 4	.30
½" x 2½" Oval Fil. H'd Screws (Socket Type)— 8	.68
½" x 3½" Oval Fil. H'd Screws (Socket Type)— 5	.55
	$24.24

The following includes all necessary place and removal (handling time), machine time, measuring time, material, and tool adjustment, plus 20% for fatigue factors, etc., based on lot quantities of not less than 10 pieces and without any special fixtures or tools.

JUNCTION A-1	$ 3.56
A-2	8.965
A-3	1.653
B-1	.728
B-2	1.07
C-1	.746
C-2	1.681
D-1	1.706
D-2	.757
D-3	.937
E-1	1.423
E-2	.895
F-1	4.85
F-2	4.85
	$33.82

Support on Junction A-2	$ .22
Support on Junction C-2	.71
Assembling Time—25 hours	31.00

$24.24+$33.82+$31.93=..................$ 89.99 (Direct Total Cost) (Subject Design.)

Note.—Additional machining, on main control valve casting, wheel slide cylinder casting, and table cylinder head castings, such as milling surfaces for joining the subject manifold junctions, will be negligible, in comparison to the number of pipe tapped holes, which the subject design will eliminate. For this reason no mention of this has been made on either of the costs.

Comparative Costs.—The conventional piping assembly used throughout the industry uses copper tubes with flared brass fittings. This design was obsoleted and replaced by existing design shown because of customer's complaint of leakages. All tubes and flared fittings inside of base were replaced by iron pipe and threaded pipe fittings, and secured rigidly to base by pipe clips and supports. This method of construction eliminated the leaks inside of base, where they were extremely difficult to get at in order to tighten. The assembly time, however, was increased and required a greater amount of space inside of machine base for assembling purposes.

Because the original piping layout is more or less standard throughout the industry, both costs are offered for comparison purposes.

DIRECT COST OF LABOR AND MATERIAL (ORIGINAL DESIGN)

Flared Brass Fittings

Symbol	Quantity	Cost
1¼" FB	1	$ 3.25
1¼" CB	1	3.25
1" FB	9	18.00
1" HBB	1	3.20
1" CB	5	10.50
1" EBB	9	28.80
1" JBBB	2	10.30
1" C45B	3	6.30
		$83.60—less 50%
		$41.80

PIPE FITTINGS

1¼" x 90° Street Elbow	2	.376
1" x 45° Street Elbow	1	.13
1" x 90° Elbow	2	.212
1" x 90° Street Elbow	1	.122
		.840 .84

Part Name	Material	Quantity	Cost
Delivery Tube (Long)	Copper Tube	1	$ 2.21
Whl. Slide-Fwd. Tube (Short)	Copper Tube	1	2.58
Whl. Slide Back Tube (Short)	Copper Tube	1	2.37
Whl. Slide-Fwd. Tube (Long)	Copper Tube	1	2.74
Whl. Slide Back Tube (Long)	Copper Tube	1	2.24
R. H. Cylinder Tube (Long)	Copper Tube	1	1.32
R. H. Cylinder Tube (Short)	Copper Tube	1	.95

Part Name	Material	Quantity	Cost
R. H. Unclamp Tube (Short)	Copper Tube	1	.78
L. H. Unclamp Tube (Short)	Copper Tube	1	1.66
Relief Tube	Copper Tube	1	.80
Exhaust Tube (Long)	Copper Tube	1	1.03
Exhaust Tube (Short)	Copper Tube	1	.33
Delivery Tube (Short)	Copper Tube	1	1.40
Delivery Tube (Short)	Copper Tube	1	.33
L. H. Cylinder Tube	Copper Tube	1	.66
Whl. Slide Fwd. Tube (Short)	Copper Tube	1	.90
Whl. Slide Back Tube (Short)	Copper Tube	1	.84
R. H. Cylinder Tube (Short)	Copper Tube	1	1.07
R. H. Unclamp Tube (Short)	Copper Tube	1	1.69
Relief Tube	Copper Tube	1	.41
Unclamp Tube (Short)	Copper Tube	1	.36
Unclamp Tube (Short)	Copper Tube	1	.50
Suction Line	Copper Tube	1	2.29
			$29.46

Flared Brass Fittings	$ 41.80
Pipe Fittings	.84
Copper Tubing and Shaping..	29.46
Assembling Cost—40 hours..	62.00
	$134.10 (Direct Total Cost) (Original Design)

DIRECT COST OF FACTORY LABOR AND MATERIAL (NEW DESIGN)

Part Name	Material	Quantity	Cost
Wheel Slide Forward Tube (Short)	Copper Tube	1	$ 1.27
Wheel Slide Forward Tube (Long)	Copper Tube	1	1.71
Wheel Slide Back Tube	Copper Tube	1	2.91
Pump Inlet Tube	Copper Tube	1	2.10
Pressure Tube	Copper Tube	1	1.64
Pressure Relief Tube	Copper Tube	1	.46
Exhaust Tube	Copper Tube	1	.22
Unclamp Tube—L. H.	Copper Tube	1	.73
Unclamp Tube—R. H.	Copper Tube	1	1.13
L. H. Cylinder Tube	Copper Tube	1	.66
			$12.83
Tube Bracket	H.R.S.	2	.92
Pipe Clip	H.R.S.	1	.86
Pipe Clip	H.R.S.	1	.43
Pipe Clip	H.R.S.	4	1.76
Pipe Bracket	H.R.S.	1	.74
Pipe Clip	H.R.S.	1	.27
Pipe Bracket	H.R.S.	1	1.89
			$ 6.87

PIPE AND PIPE FITTINGS

1″	x 90°	Elbow	2	.212
1″	x 45°	Street Elbow	3	.39
1″		Gas Cock	1	.82
1″		Close Nipple	7	.3178
1″	x 45°	Elbow	4	.52
1″	x 90°	Street Elbow	6	.732
1″		Tee	1	.1378

1"	x 90°	Female Union	3	2.115
1"		Plug Cock	2	1.00
1¼"	x 90°	Street Elbow	1	.188
1¼"	x 90°	Elbow	1	.164
1¼"		Close Nipple	1	.059
1¼"	x 45°	Street Elbow	1	.27
1"		Coupling	4	.92
1"		Pipes (All lengths threaded both ends)		12.34
				$20.19

FLARED BRASS FITTINGS

Symbol		Quantity	Cost
1"	CB	4	$ 8.00
1¼"	CB	1	3.25
1"	FB	5	10.00
1"	JBBB	1	5.15
1¼"	FB	1	3.25
			$29.65 (Less 50% $14.83)

Flared Brass Fittings	$ 14.83
Pipes and Pipe Fittings	20.19
Pipe Clips and Brackets	6.87
Copper Tubing and Shaping	12.83
Assembling Cost—60 Hours	93.00
	$147.72—DIRECT TOTAL COST (Existing Design)

TOTAL COST

Existing design	**$147.72**
Arc Welded design	**89.99**
Savings by Arc Welding	**$ 57.73**

Proportionate Cost Saving:—This shows a proportionate cost saving over previous existing design of 39% and over the original or conventional method of construction of 33%. The latter cost saving is submitted because it will apply to industry in general, when conventional method of flared tube fittings is used.

Chapter XVI—Arc Welding Applied in Pressing Machine Manufacture

By Ernest Davis,
Chief engineer, Prosperity Co., Syracuse, N. Y.

A brief history of pressing machines will be outlined as an introduction to this paper in order to set forth a background for the development of the latest type machine manufactured by the company, which is to be described in detail in this paper.

The first pressing machines developed for use in laundries, for pressing wearing apparel processed in laundries, were equipped with a padded

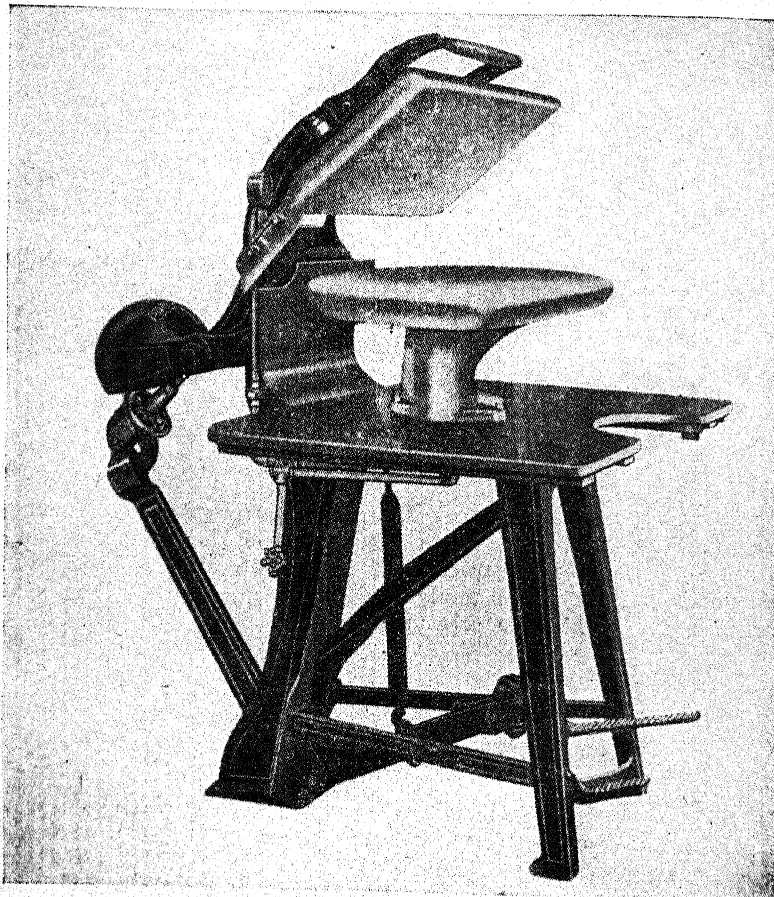


Fig. 1. One of the first pressing machines. Construction—cast iron.

platen on which the garment was laid, and a highly-polished, heated platen arranged to be brought into high pressure contact with the damp garment to effect removal of wrinkles and moisture and give the garment an ironed finish. Fig. 1 shows one of the first of such machines manufactured by The Prosperity Company.

It will be noted that this machine was equipped with a simple toggle lever mechanism and a foot treadle for manual application of pressure. The polished, steam heated platen was balanced by a counterweight in the rear, and a handle was provided on the upper platen for pulling the platen into pressing position.

This machine, except for the wood handle, table, and piping, was made entirely of cast iron. This machine developed more pressure on the ironing surface and consequently a much better ironing finish. It was mostly built of cast iron, and the unwieldy cast iron counterweight was still retained.

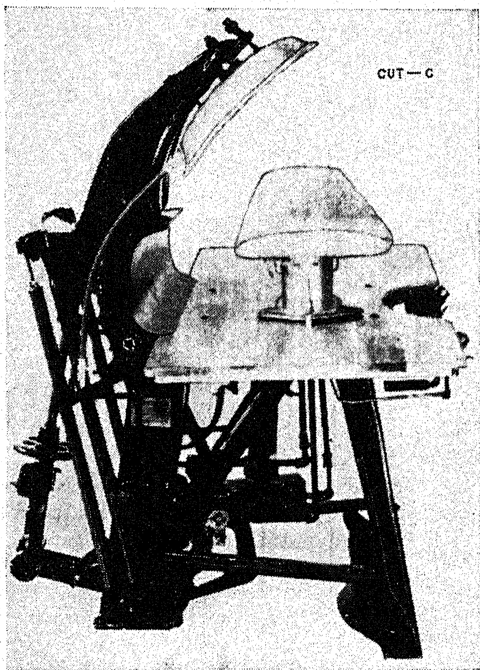


Fig. 2. Pressing machine which preceded new arc welded steel unit.

Fig. 2 illustrates the type of machine manufactured by the company in 1937 and part of 1938, and which is replaced by the latest development which is to be described in this paper. This machine is still somewhat heavier in construction than former machines and is provided with larger ironing platens. This concludes a brief history of past developments.

Fig. 3 illustrates the very latest development in pressing machine design and manufacture. This development is to be described fully in the following pages.

The original machines described were manufactured by The Prosperity Company for about twenty years. Laundryowners and workers in all civilized countries on the globe were acquainted with the general appearance of these machines.

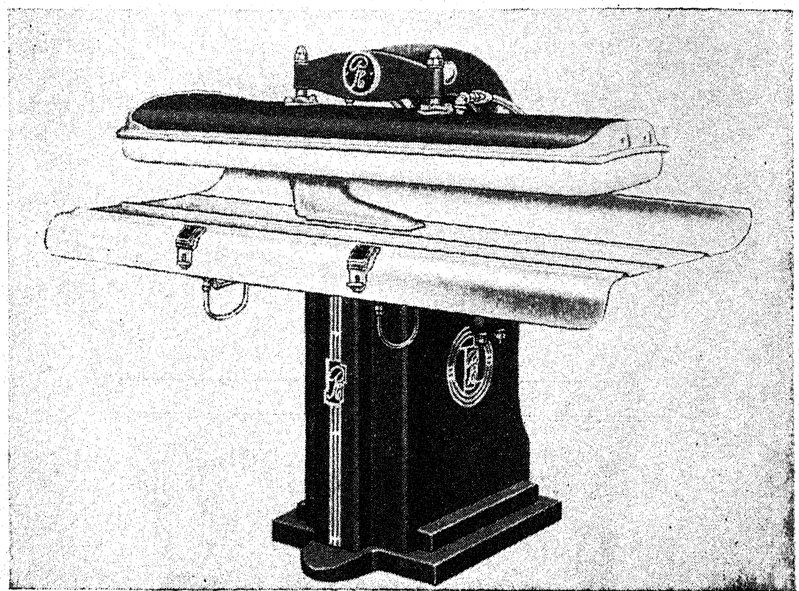


Fig. 3. Latest development in pressing machine design and manufacture. Construction—arc welded steel.

It follows, therefore, that it was mandatory when the company decided to enter into the manufacture of a really new pressing machine, especially in appearance, that the engineering department consider all possibilities from the standpoint of salability and manufacture. The following requirements were considered—

1. The new machine must be superior in performance: A, from a standpoint of quality of work produced; B, from a standpoint of quantity of work produced; and C, it must be quiet and smooth in operation.
2. It should be modern and pleasing in appearance.
3. It should be modern in mechanical design.
4. It should occupy less floor space.
5. It should be more efficient in the use of air power.
6. It should be more flexible in operation and adjustment.
7. It should be less liable to breakage under operating conditions.
8. It should lend itself to modern methods of manufacture.
9. It should be so designed as to provide for standardized interchangeable manufacture of a complete line of pressing machines.

This paper shall attempt to describe how these nine points are best attained by the use of a steel fabricated, arc welded design.

Point I, Superior Performance.—

A. The quality of work produced on a pressing machine is very much dependent upon the pressure applied between the upper heated platen and the padded heated platen on which the garment is laid.

The first laundry pressing machine delivered a total pressure between the platens of approximately 1200 pounds. On the average size platen this would equal about three pounds per square inch applied to the surface being ironed.

The latest Prosperity steel press will deliver a maximum total pressure of twelve thousand pounds, or about 25 pounds per square inch depending on the size of the platen.

The rigidity of the stress members in a press bear a direct relation to the power required for a given total pressure. Steel being stiffer than

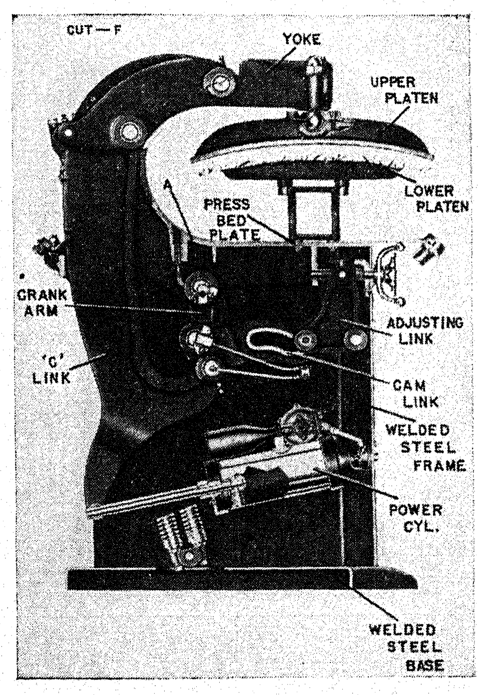


Fig. 4. Cross section of pressing machine.

cast iron serves as a better material. In Fig. 4 we have a cut showing a cross section of the press. The main bed plate "A" is cast in steel in order that it may be arc welded to the steel plate side of the frame. After the frame members are welded to the base we have the completed pressing machine frame. Farther on in this paper we shall show how the several

parts of the old cast iron frames were bolted together providing a framework which was very inefficient from the standpoint of rigidity, especially when the bolts stretched and became loose. This is perhaps one of the first and most important points in the steel fabricated arc welded construction.

B. Naturally, more rigid construction provides for faster, smoother application of power in closing the platen. These are factors affecting the amount of work which may be turned out on the machine.

Point II, Modern and Pleasing In Appearance.—A very casual comparison of the appearance of the old and new design should be convincing on the above points.

It might be agreed that it would be possible to provide the same pleasing design in cast iron, but for the same strength and rigidity the cast iron design would certainly be very much heavier and more costly, as will be shown later by a comparison of costs. A laundry is selling cleanliness. It follows that a laundry should express just that in general appearance of plant and equipment.

The new model press, with all operating mechanism enclosed in the steel base and finished in smooth, high-gloss, baked enamel finish, is much easier to keep clean. Very few bothered to keep the machines of the old design cleanly in appearance. It is believed that this new design pressing machine is a step toward the laundry of the future,—machines all done in white enamel, tile floors, and tile walls.

One other important item in connection with painting must be mentioned, and that is the painting of smooth plate steel is much simpler than filling and painting cast iron. The paint is simply sprayed onto the steel and put directly into the oven. Figures showing savings in cost in this procedure will be shown in the cost analysis at the end of this paper.

Point III, Modern In Mechanical Design.—A comparison of many detailed features in the new press and the old press will indicate many improvements and a tendency towards modern practice in mechanical design. For example, all heavy duty bearings in the new press are of the anti-friction type, fully enclosed with ample provision for proper lubrication. Such assembly units as the main power cylinder, where necessity for easy assembly and perfect alignment are important, are equipped with ball and socket mountings. All working parts of the machine are enclosed in the fabricated steel housing. The work table is of steel with a baked enamel finish instead of wood as in the old machine.

The hydraulic governor which controls the smooth opening and closing of the platens is directly connected to the main shaft instead of being simply attached by link mechanism, thus controlling the entire movement of the mechanism in a more direct manner. In the former design the check, or governor, was added to the old design simply as an afterthought, not being incorporated in the original design. The specially designed governor is attached to the side of the steel frame.

The balance springs for the platen are carried within the frame and are mounted on a shaft extending through the base. This shaft is supported by ears welded into place on the base, as will be clearly shown by reference to the base design. Since these springs support the entire

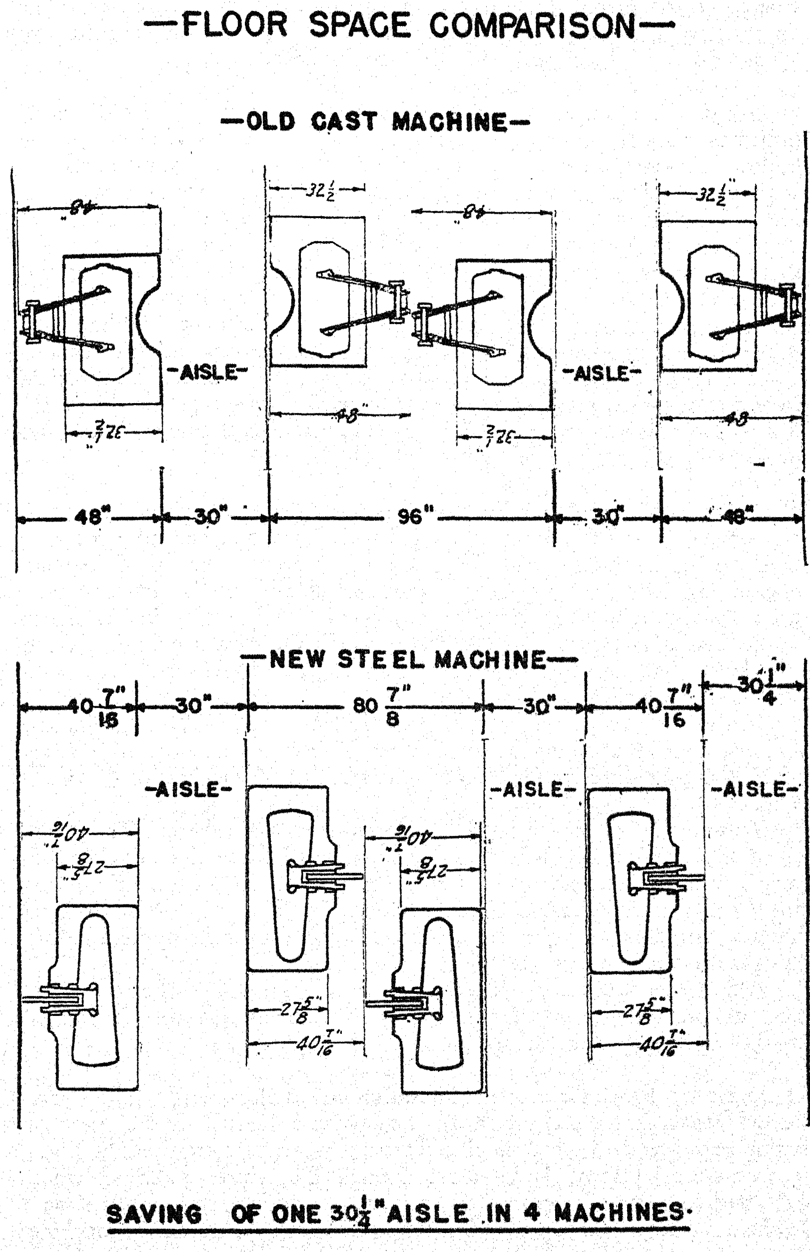


Fig. 5. Graphic comparison of floor space required for old cast iron, (above), and new welded steel pressing machines.

weight of the platen and serve as a means to return the platen to its open position, the springs and their supports must not fail or injury to the operator might result. Welded steel is SAFE.

Point IV, Occupies Less Floor Space.—A study of the old design indicates a scattered arrangement of mechanism. By making use of the hollow, enclosed, steel frame of the new design, all working parts are brought into closer relationship, and a saving of floor space of about eight inches from front to back results in a reduction of total square inches of floor space amounting to 16%. (See Fig. 5). In large laundries where there are several rows of machines, for each four rows of the new machines we save 30″ working aisle space. This is very important where in some cases additional machinery might require additional building construction, and in some cases buildings are so located that additional floor space cannot be provided. By the use of the new machine it is possible to add about 40% more production in a given floor space. This is partly due to the reduction in floor space required and also due to the increased production of the new machine.

Point V, More Efficient In the Use of Air Power.—It has previously been stated in this paper that the rigidity of stress members in a pressing machine increases the pressure applied for a given outlay of mechanical power. By actual tests it has been determined that in the first cast iron frames manufactured by the company the lack of rigidity in the frame resulted in a loss of 66% of the power used. The power cylinder of the old design had approximately 120 cubic inches displacement and was slow in compressing the pad.

In the new design the cylinder has displacement of 119 cubic inches, and will deliver a maximum total pressure between the pressing platens of 12,000 pounds, assuming a total compression of padding of ⅜ of an inch.

This amount of power closes the platen about 40% faster. The greater pressure and faster buildup of the pressure in the new machine, is very important because it bears a direct relation to the smoothness of finish of garments ironed. That is, when the platens are brought into contact with the damp garment the total pressure must be applied before the garment has a chance to dry.

Although not all of the above increase in efficiency is due to welded steel design, a large percentage of the increase is due to the greater rigidity of the welded steel unit.

Point VI, More Flexible In Operation and Adjustment.—The lower heated platen is padded generally with what is known in the trade as spring padding, over which is placed several layers of cotton padding and two or more layers of double-faced flannel. The cotton padding, when subjected to repeated applications of pressure and moisture, packs down. In the old machines this resulted in the loss of pressure unless the machine was frequently adjusted. In the new steel design this frequent adjustment of pressure is avoided by provision for ⅜ to ½ inch follow-up on the pad. This is done through an improved power mechanism. This greater follow-up, however, would require proportionately more power

in a frame of less rigid construction. Any looseness of the frame members would result in a loss of power and adjustment. A reference to Fig. 6 showing the number of parts and bolts in the frame of the old machine will make this point clear, even to one not familiar with pressing machine design.

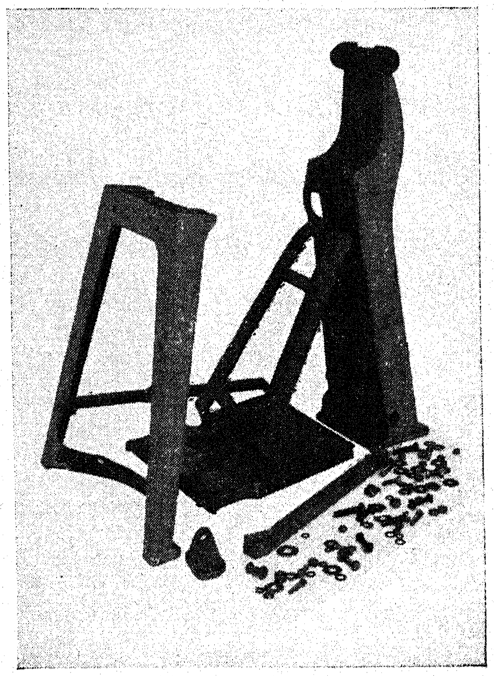


Fig. 6. Parts and bolts of old cast iron frame.

Point VII, Less Liable to Breakage.—The high factor of safety required when figuring strength of cast iron as compared with rolled-steel welded construction generally contributes to awkward, heavy, unwieldy designs where weight is not desired.

Breakage of the cast iron members of the frame on the earlier presses was very costly in many ways, that is: A. From a service and replacement standpoint; B. From a sales and good-will standpoint; C. Handling cost; D. Inventory; E. General over-head, including the cost of carrying, over a period of many years, numerous old patterns which must be kept in repair, and all office work required in connection with providing for the furnishing of old parts. Occasionally a back leg, yoke, or center brace of a machine twenty years old may break and it is important, if the company is to maintain their good-will in the trade, that they be able to furnish this part, or these parts, on short notice. It is expected that in the future we shall never be called upon to furnish any part of the new steel frame and important stress members in the new machine.

Point VIII, Modern Methods of Manufacture.—The various items in connection with manufacturing, especially indirect items of general over-head, are effected by the new steel press design.

A. The most noticeable advantage in connection with production of the new steel press is reduction in the number of parts in this design over the old design.

In the old design a single frame was made up of seven separate castings machined and held together by approximately seventy-six bolts, washers, and nuts as shown in the photo of the old frame, Fig. 6.

Today, the welding department turns out a complete, welded, steel frame unit, all welding and gas cutting being done in the one department.

This main, welded assembly, after passing through the paint department on the way, meets a few other machined assemblies on the assembly line, and we soon have a pressing machine ready for the shipping department.

In other words, the welding department completes the most important item, (the frame), except for one set-up in one fixture for complete machining. This results in shorter and more direct routing of materials through the factory.

B. As stated before, in painting the frame requires no filling before spraying, especially since the stampings come very smooth and the complete painting of the frame is done in a few minutes. Since most of the working parts are carried within the frame no retouching of the frame seems necessary after the final assembly, whereas in the old machine, since the parts were mounted all over the frame, retouching was done after the final assembly.

C. By reference to Fig. 4, showing a cross section of the completed machine, it is evident that there are a fewer number of sub-assemblies. These are all bench assemblies instead of floor assemblies. This speeds up the final assembly.

D. The parts storage space required for the new steel machine is greatly reduced. The side plates of pressed steel, when stacked, occupy very little space. One thousand pairs of steel plate sides is approximately one carload, or enough for $600,000 worth of pressing machines. The casting storage space required for the old machine frame was about three times as great, especially since these castings were filled in the receiving casting room and it was necessary to set these castings out separately in order to allow for drying after the filling operation.

E. Since all link mechanism and mechanical parts of the frame are completely tooled for interchangeable manufacture less skilled labor may be used in the assembly. In the old frame even though the parts were fully machined the frame had to be lined up in assembly by expert workmen.

Because of a possible misalignment of parts of the frame there was ample opportunity for misfits in various assemblies when applied to the frame. Also, the frame being made of green castings, which may have warped after machining, caused faulty assembly of the frame.

F. In the new steel frame, small holes and some large ones are punched in the frame during the stamping operation. The three holes not punched are drilled in the main fixture after the frame is welded and before reach-

ing the assembly line, whereas in the old cast iron frame there were holes in several parts which should line up with holes in other parts after assembly. This resulted in slow and poor final assembly. The old frame, because of its peculiar design, and weight, did not lend itself to the application of one single fixture for locating all drilled holes or milled spots.

As the shop continues building the new machine other advantages in connection with modern methods of manufacture will appear possible.

Point IX, Provisions for Complete Interchangeable Line of Presses. —The complete line of garment presses comprises several types of machines, and approximately a dozen models in each type, listed as follows: —A, Laundry type presses air operated; B, Clothing manufacturing type presses air operated; C, Tailor types foot and air operated; D, Dry cleaners type air and foot operated; E, Knit goods type air operated; and F, Special presses for collar and shirt manufacturers', leather finishings, etc.

While it may not prove advisable to include all the different type presses in the one design of frame and lever mechanism, it is contemplated to build practically all of the above types on the one steel frame.

Formerly there was a different frame and power mechanism for not only the different types, but in laundry presses there were two sizes of frames and several different types of sides braces, center braces, yokes, etc.

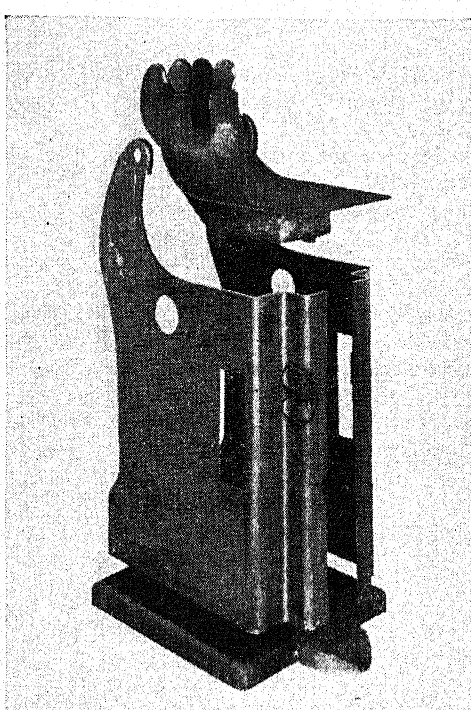


Fig. 7. New arc welded steel frame of pressing machine.

Some of the above types of machines were heavy duty and others light duty. With the old cast iron frame certain members of the heavy duty machines would have been much out of place used with parts for the lighter duty machines. For small platens the heavy frame was much too cumbersome, especially on foot operated types of machines.

The new fabricated steel frame, (See Fig. 7), because of its much lighter weight, its more compact design, its greater strength, is strong enough for the heaviest duty machines and light enough and compact enough for the smaller machines and those used for lighter duty. Therefore, the steel fabricated frame will serve over a wide range of different types and models of machines, and will provide for interchangeable manufacture of practically a complete line of pressing machines.

The above point is, probably, one of the most important points in connection with the new steel frame, since it is designed so that it may accommodate a power mechanism or, with slight changes, foot operated mechanism, and also what is known as semi-automatic power mechanism where both foot operation and power operation are combined in one machine.

Comparative Cost Analysis.—In view of the following: A, the very much greater working capacity; B, the nine points of superiority; C, the specially designed, much more expensive hydraulic governor; D, the roller bearings instead of cold rolled steel shafts on plain cast iron bearings; and E, complete self-aligning mounting of upper platen it is not equitable to make a direct comparison between the cost of the old design and the new—in view of these points, the cost analysis will show a cost comparison between the new frame of arc welded design and the old design assuming equal load capacity.

In order to satisfy the conditions of this comparison it will be necessary to figure the stress members of the old design on the basis of using steel castings. Even this alone would not entirely satisfy the conditions, since in the old design it would be necessary to use a greater number of bolts to tie the frame members together. Naturally, the old design without changes will not accommodate the more expensive bearings, shafts, hydraulic governor, finish, design decorations, self-aligning platen, etc.; and would exclude the far greater sales appeal from the standpoint of appearance, reduced floor space, greater speed, increased production, and the finer quality of work produced by the new design.

However, one very definite cost comparison may be made between the complete machine of the new design and the old design. The model number 554 press weighs 1135 pounds, the model number 554, old style machine, weighs, 1435 pounds; showing a difference in total weight of 300 pounds. The 300-pound difference in weight of the new style machine will naturally make some difference in shipping costs.

It is a little difficult to arrive at an average figure for shipping cost since there are so many different ways in which machines are transported, truck rates, water rates, special carloading rate, etc. We shall, therefore, for this cost comparison assume the shipping rate from Syracuse to Chicago. Prosperity machines are shipped all over the world, therefore we may at least assume for the United States that the shipping rate to Chicago would represent a very conservative estimate of the average rate

per hundred for shipment. The rate from Syracuse to Chicago is $1.14 per hundred. This would represent a saving in favor of the new machine of $3.42 per machine.

The open car rate from Syracuse to West Coast is approximately $5.50 per hundred. On the basis of assuming $3.42 as being the average saving per machine for shipping costs in favor of the new design, this saving alone to the company or purchasers, assuming a very low normal rate of production for the next year, should amount to a total of about $18,000.00.

Naturally, this difference in weight will even affect the handling costs in the factory, although it is believed no figure can be reasonably estimated for this difference.

Out of the cost figures for the two frame designs which will follow, we may call attention to the fabricated steel base, the material amounting to $1.95, the labor including welding complete $ .50, total cost $2.45.

We have estimated that to produce as satisfactory a base in cast iron, figures would be as follows:—

152 lbs. of cast iron @ 5¢ per lb.	$7.60
Labor	.25
Total	$7.85

For the sake of comparison, if we wish to duplicate the new steel design frame in cast iron, figuring the frame fully enclosed as in the new steel design, the cost comparison would be as follows:—

Two pressed steel sides cost	$6.01
Labor including welding	.19
Total	$6.20

It may be estimated that even designing an open framework of cast iron and putting steel panels in the sides, a cast iron frame in order to match the appearance of the new pressed steel design, would weigh for the two sides in cast iron about 300 pounds. At 5¢ per pound, and assuming a very low labor cost for grinding and filling of 25¢, the cast iron sides would at 5¢ per pound amount to about $15.00.

On Basis of 5000 Machines for 1938 Frame of original design, in cast steel for equal strength, machined and bolted assembly, from cost, regular Model	$46.35
New Power Circle frame, complete	21.71
Difference	$24.64

$24.64
x 5000

$123,200.00=Total cost savings for 1938.

Chapter XVII—Design of an Asphalt Paving Plant of Maximum Capacity, Minimum Weight and Maximum Mobility

By Robert C. Shoemaker,
Engineer in charge of equipment, Warren Northwest, Inc., Portland, Ore.

General Description of a Paving Plant.—A paving plant may be briefly described as the central mixing unit in the so called "hot mix" or "plant mix" type of asphaltic concrete highway construction. In this plant, cold moist sand and crushed rock, known as mineral aggregate, is dried and heated so that it will properly mix with the cementing medium, asphalt. In order to obtain a dense and accurately controlled mixture, the aggregates are carefully screened into separate bins from whence they are drawn into a weighing hopper in predetermined proportions and subsequently discharged into a pug mill mixer where a fixed quantity of asphalt is introduced. After the required mixing time, the mixture is deposited into trucks for transportation to the road where it is spread in layers usually about 2″ thick and compacted by rollers to make the pavement surface, commonly known as "Asphalt".

In the early days of the industry, the great majority of asphalt plants were placed in more-or-less permanent locations for use in paving city streets. At that time, plants were very seldom moved, for which reason their design was restricted almost entirely to cut and try, with a factor of safety based on the time honored slogan of "Make Things Heavy Enough". Similarly, very little attention was paid to restricting the size or shape of component parts of the plant to permit easy transportation without almost complete disassembly. This was partly due to the fact that transportation almost invariably was by rail and large weight and size, although undesirable, were not prohibitive. Another characteristic of early designs was an almost complete disregard of the details of erection. It was always assumed that a gin pole or derrick was absolutely necessary and therefore no effort was made to provide for handling any of the component units in any other way.

With the more general adoption of the plant-mix type of pavement to State Highway work, it became necessary to move paving plants more often than heretofore and to localities frequently far beyond the reach of the railroad. Coupled with this general trend, we have been confronted with an ever tightening highway restriction with regard to weight, height, width and length limits. To make matters more difficult, we have been required every year to produce plants of greater capacity to keep pace with developments in mixture spreading equipment and high speed trucks which are now available to deliver mixtures from the plant to the road.

It is therefore apparent that every trend of requirements tends to

make the design more difficult and refined. Fortunately, however, the very factors that stiffen the requirements are also available to serve in their solution. None the least of these advancement factors is the technique of arc welding, without which, the design herein described, would be manifestly impossible.

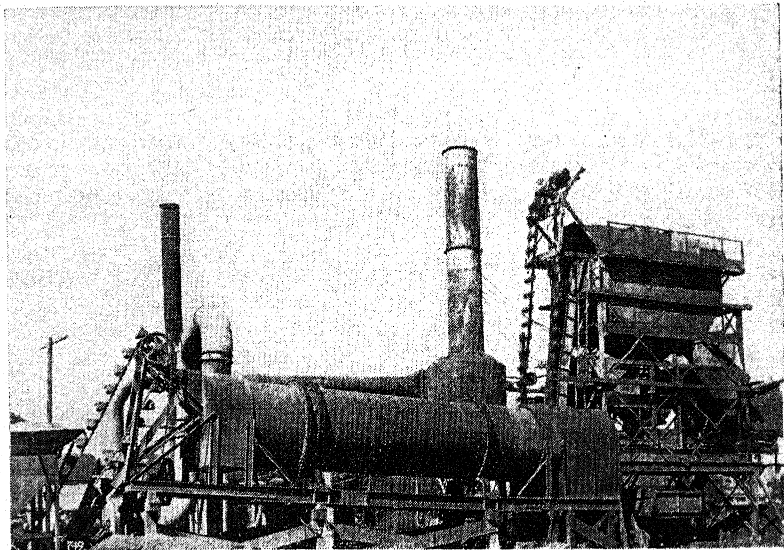


Fig. 1. The arc welded paving plant in operation.

Before going into the details of this particular machine, (See Fig. 1), one very important, but frequently unrecognized factor, should be pointed out. Reference is made to the mere cost of engineering, which in this particular type design bears an abnormally large relation to the cost of construction. To further understand this point, it should be realized that the entire basic design had to be changed in order to stay within the weight and size limits imposed by the State Highway Departments, in order that the plant might be economically transported from job to job. As an example of the extremes to which we had to go, the reader is referred to photograph, Fig. 2, wherein we show Unit A ready for transportation. As subsequent text will reveal, the photograph shows a bucket elevator head-rig within a screen; the screen within a bin, and the bin within three sections of tower collapsed one within the other. As there were no previous similar details to follow or alter, the amount of original engineering and detail work that was required was tremendous and would have been of prohibitive cost, had it not been for the many simplifications of detail made possible entirely through the use of arc welding.

In order that the reader may get a conception of the entire machine, its problems and their solution, complete description will be given herewith. This will be followed by a discussion of the important part played by arc welding in many specific details.

Description of the Plant under Discussion.—The plant is divided into three main units, known as Unit A which includes the Tower, Bin and Screen; Unit B which includes the Mixer, Scales, Weigh Box, Levers, etc., and Unit C, the Drier. Additional equipment which has been assembled for specific use with this plant, consists of dust piping, dust collector and dust elevator. No special requirements are imposed on the blowers, boiler, asphalt pump, tanks, general piping and power plants so these latter units will be omitted from the following discussion. Power is supplied either by diesel engines or electric motors, depending on conditions.

Nearly all drive chains, line shafts and counter shafts found on other designs have been eliminated on the theory that they are both dangerous and expensive. Separate motors are used instead on minor drives and a diesel generator provides power where utility power is not available.

The entire plant is of welded construction, resulting in simplified steel details and considerable weight saving, details of which will follow. An effort has been made to properly proportion all members so as to give an efficient and balanced design without excess weight and we believe our efforts in this regard have been successful, as the plant is truly light for its capacity and no structural failures in welds or steel have developed up to time of writing after about thirty thousand tons production.

We feel conservative in saying that nothing has been sacrificed in the effort to keep the plant within dimension limits imposed by state highway departments, nor have sacrifices of efficiency been made to carry out the general erection and transportation schemes. The design was made for eighty ton per hour capacity and production has exceeded this figure by a fair margin in many instances.

Transportation.—All the units are so designed that they can be transported legally over the highways of Oregon, Washington and Idaho behind any standard truck. Briefly the State laws impose the following limits: Width 8′, Height 11′, Length, including tractor truck, 50′, maximum axle loading 13,000 lbs. It is not possible to have every axle loaded to the maximum, as additional restrictions are placed on total gross load, and certain axles are further limited to less than 13,000 lbs.

Due to these limitations, great refinement in design was required throughout, not only to save weight but also to make a compact unit that would remain entirely within the 8 ft. width and 11 ft. height limitations. The weight factor with this machine is of far more importance than the weight factor with most designs because we are not only concerned with the additional expense that weight entails and the additional freight on this weight but we, throughout the entire design, approached dangerously near an absolute limit beyond which it was impossible to go and yet maintain our objective of portability.

In order to save investment in wheels, tires and axles, we have built the dual axle rear truck, as used in Unit A, and the front pony trucks and fifth wheels into complete removable units. After delivery of Unit A, the trucks are removed and returned for installation under

the Drier which rides on the same license and public utility commission plates as Unit A.

These units have all passed police inspection for licenses in the State of Oregon, are equipped with air brakes and have been successfully trailed nearly a thousand miles through Oregon and Washington attaining safe speeds up to thirty miles per hour.

Foundations.—The use of expensive concrete foundations, as has been customary in the past, is completely eliminated, as this plant is designed to stand on simple timbers, the bearing area of which is ample even on top of the ground.

Erection.—After the main foundation timbers for the tower have been placed, and leveled, Unit A is rolled on its wheels over them so that the bearing plates at the bottom of the tower legs will come immediately above the timbers. Construction of Unit A is such that with the removal of two bolts, the rear tower legs will slide down onto the timber without requiring the removal of the rear wheels. It will be seen from Fig. 2 that, if the plat were perfectly level, the elevation of footing plates would be exactly right for the top of the timbers. To get the front tower legs into bearing on the timbers, it is necessary to jack under the front yoke enough to relieve the weight, pull the king pin, roll the front pony truck out and then lower the legs onto the timber.

Raising Tower.—With the tower legs properly bearing on the foundation timbers, the next step is to raise the tower by means of four winches permanently installed on the frame. The design is such that the bin remains on short legs at the ground until the tower has been completely raised, all bolts installed and all diagonals tightened. The first lift raises the upper two tower sections (one inside the other) pulling through snatch blocks hung at the top of the lower section. The middle section is then bolted to the lower section while the blocks are installed at the top of the middle section. Cables from the winches are now run over each of these blocks, respectively, and are fastened to lugs welded at the lower end of the upper tower section so the upper tower section can be raised.

Raising Screen.—The cable blocks are now installed at the top of the upper section of the tower where proper brackets are welded on and the lines are brought down to the screen where hoisting lugs are provided. The screen which is transported inside the bin is now raised so that it will assume its final position on top of the bin. The cross beams that hold the screen rise with it and are bolted when the proper position is reached.

The next step is to fasten one of the cable lines to the elevator head assembly which has been hinged down for transportation in the screen. Pulling on the winch raises this assembly to its final position which is nearly vertical, at which point the braces are bolted in place.

Raising Bin.—The four winch lines are now fastened to the bin at lugs welded to the main bin supporting frame, and the bin with

screen and elevator head-shaft all raise so that they project out the top of the tower at the elevation of their final position where the assembly is permanently bolted to the tower.

The elevator head assembly is mounted so it will slide out, in order for the buckets to clear the bin and tower, which operation is also done with the winches.

Before elevating the bin, six bolts that hold the rear truck to the bine frame are removed so that the wheels remain on the ground, where they can be rolled out of the way. Fig. 3 shows Unit "A" nearly erected.

Placing Unit B.—When the tower has been erected, the way is clear for Unit B (the mixer floor), which is made narrow enough to roll in the end of the plant between the tower legs. The end cross bracing at the lower part of the tower, is made up as a removable unit (light enough to be handled without tackle) and after its removal, the portal in the end of the plant is high enough to admit Unit B complete as it rolls over the top of the foundation timber. To avoid the difficulty that would be experienced in getting unit B "aimed" straight and headed for the portal, the leading end of it is raised clear of the ground by the two winch lines on the corners concerned. It is then a very simple matter to swing it into exact position and elevation and to get it level so it will not foul the portal on the way in. Power to pull the unit in is provided by the other two winches which have proved themselves ample even under adverse conditions. It should be noted that Unit B enters the tower, rear end first which simplifies the matter of getting it to its primary location while it is still coupled to the truck that tows it to the site. The truck is disconnected before the unit is pulled in under the tower, however, as this work can best be handled by the winches alone in the manner described.

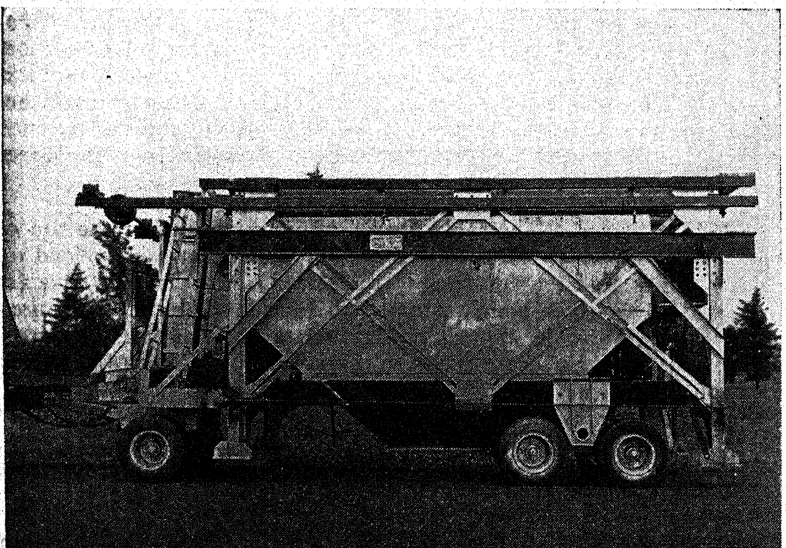


Fig. 2. Unit "A" of paving plant in transit.

With Unit B in place, under the tower, (See Fig. 4), it is a simple matter to raise it to its final position with the four winches, leaving the wheels on the ground. In its final position, both ends of the main frame beams bear directly on substantial tower cross members and Unit B becomes an integral part of the structure.

It has been pointed out that all the intricate lever and scale systems of the plant remain in working position during the entire process of erection, transportation and dismantling, so with the final placing of Unit B, this part of the plant is practically ready for operation.

Installing Elevator.—After the pony truck from the front end of Unit A has been removed, the hot stone elevator tail shaft is swung down into place on its hinges, where it is fastened with a few bolts. Here again one of the winches may be used. The bucket string is then put in place with the aid of two winches using one to pull up and the other to pull down. The elevator idler is never removed so is automatically in place.

Minor Parts.—The return spill chute, which is made in three sections and goes up with the tower, is practically in place when the tower is up and the ladder is mounted similarly. It will be noted that there are practically no parts on the plant which are removed when the plant is dismantled, and the few parts that are removed are small enough to be readily handled by one or two men without tackle of any kind. Definite provisions have been made for mounting snatch blocks and fastening cable to facilitate all lifts and eliminate the danger of improper fastenings. The whole plant can be and has been erected and dismantled complete without the use of gin pole, derrick or power.

Erection of Drier.—In order to keep the length of the drier within legal limits, the design was arranged to permit removal of the feed-end housing with elevator frame and the discharge end housing with combustion furnace combined with the sub-frame of each. The drier therefore arrives at the plant site as a trailer which carries the drum proper with its sub-frame, trunions, etc. The two end assemblies are transported on flatbed trucks or trailers. (See Fig. 5).

Placing Discharge End Assembly.—The first step in erection of the Drier is to place the combustion furnace end in position beside the hot stone elevator. To facilitate this operation, small car wheels have been mounted under the assembly (weight about 6 tons) and the bents on which it is mounted are framed together with rails to carry the wheels. Fastened to the bents with two pins is a ramp track about four feet long which also fits the wheels. The combustion furnace is transported on the flatbed of a trailer, preferably on short pieces of rail so that it can roll off the side of the trailer onto the ramp track and up onto its permanent foundation bents. Power for this operation is provided by one of the winches.

Placing Drum.—Due to the fact that the plant is usually set up next to a stock-pile, which limits the room that would be required for the tractor truck that puts the drier in place, we have placed the front pony truck on the end of the drier which comes next to the hot stone ele-

vator. The drier is therefore backed in, approximately parallel to the tower, but at such an angle that the rear trucks will cross the center-line of the final drier location. When the rear trucks are on this center-line, the tractor truck is detached from the draw bar and the front pony is pivoted so the wheels will roll in a direction perpendicular to the center-line. By reconnecting the truck to the draw bar in this new position, the front end of the drier is pushed in, toward the center-line and the rear end pivots about the center of the dual axle rear truck. The front pony truck is now straightened out again so the drier can roll down the center line and a timber ramp about 1 foot high is placed in front of the wheels. With the aid of two winches pulling on the draw bar, the drier is pulled forward, up this ramp so the drum shell enters the discharge housing. The next step is to jack up the rear end of the drum to its permanent elevation, leaving the rear truck on the ground where it can readily be rolled out of the way. Permanent bents are provided to be placed under the frame of the drier and these are cross braced, one with the other, forming a veritable table about 9 ft. wide and 15 ft. long.

Component Parts, Drier.—The drier drum is 72″ in diameter by 26 ft. long made of 5/16″ plate all welded construction. The feed end, housing and discharge end housing are made of 3/16″ plate. The main frame is made of heavy 12″ CB sections. Tires have a 6″ face and are mounted on brackets containing wedges so they can be centered when drum warpage would tend to throw them out. Wide reinforcing bands are welded around the drum under the tires. Trunnions are 24″ in diameter of plain cast iron with bronze bearings. 8″ channels are welded in the drum for flights. Power for driving the drier is applied on a pulley at the cold stone elevator end, rotating on an axis parallel to the center-line of the drum. Speed reduction is obtained through a set of cut tooth steel gears, the driven member of which is mounted on a shaft carrying the final drive sprocket. Final drive is with sprockets and chain rather than through gears. The cold stone elevator is driven by chain from a cross shaft mounted to the lower part of the frame which in turn is driven through a pair of mitre gears.

Elevators.—Both elevators are equipped with standard buckets, mounted every fourth link on a single strand of chain. The 24″ head wheels run at 39 rpm, giving a bucket speed of about 245 ft. a minute. Frame and housing have been eliminated from the hot stone elevator, as head and tail shafts are rigidly mounted to the tower frame.

Power for the hot stone elevator is provided by a 10 HP, totally enclosed, fan cooled, dust proof electric motor mounted above the head shaft. This motor is direct connected to a totally enclosed ball bearing, herringbone, speed reducer which in turn drive the head shaft through a roller chain. Speed changes in the elevator are possible by changing the sprocket on the driven end of the speed reducer and adjustments in chain length are made through a readily adjustable idler sprocket mounted to the frame.

Screen.—The screen used is a 12 ft. x 42″ double deck vibratory formerly used on a crusher set-up. The screen is rigidly mounted to

the bin on three cross channels and the elevator head shaft bracket is mounted to the main screen channel in a manner described above under the heading "Raising Bin". No trouble, has been experienced from excessive screen vibrations being set up in the plant and even the scales are apparently undisturbed.

A cover has been provided for the screen, made up in three sections each of which is small enough to be handled by two men. These sections are equipped with handles and so designed that they can be nested one on top of the other when it is necessary to work on the screens. A catwalk with a railing, all of which folds up into the bin, has been provided at the top of bin for convenience. A man can walk around the catwalk in perfect safety while the plant is in operation.

Power for the screen is provided by 5 HP totally enclosed, fan-cooled dust proof motor connected through V belts.

Bin.—To permit the screen to slide down inside the bin for transportation purposes, the partitions, of which there are three, are hinged at a point about 4 ft. down from the top in such a manner that they can all be laid flat.

Due to the hinging feature, it is not possible to support the bin partitions except at their edges. It was therefore necessary to provide particularly rigid fins on the sides of the bin to which the partitions are bolted. These fins or webs are designed in such a manner that they give great rigidity to sides of the bin to resist the tendency that the partitions would have to draw the sides of the bin inward. Also, when the plant is run without partitions in place the tendency of the bin to bulge from rock pressure is resisted.

The overflow from the bins, with the exception of No. 1, is taken care of by small chutes which run inside the bin to the back end where they discharge into an overflow hopper. The chutes are permanently mounted and do not have to be moved during erection or dismantling. They are placed at one side of the bin so that they do not foul the screen when the latter is lowered into the bin for transportation. Starting with the standard screen in the center and adding space for these overflows, left a very limited margin within which the entire collapsible tower had to be built. It is for this reason, that even the thickness of overlapping gussets and rivet heads would have made it nearly impossible to stay within the allowable eight foot overall width.

There is a large size rejection chute fastened to the screen and mounted outside the bin which takes care of guiding reject material to the hopper below.

Weigh Box and Aggregate Scale.—The Weigh Box is one of 3,000 lb. capacity of standard welded construction. It is equipped with double swing gates, operated by a compound lever system, and is hung from the Unit B superstructure frame on a suspended dial scale.

Asphalt Weighing.—Asphalt is weighed in a cylindrical welded bucket which is suspended from a beam scale with over-and-under indicator.

Mixer.—The Mixer is a 3,000 lb. capacity standard design pugmill. It is equipped with steam ram for opening and closing and is driven by a separate motor or engine of 75 to 100 HP capacity.

Control Deck.—Arrangement of all levers and controls is such that the entire plant, with the exception of the drier, is operated by one man who stands beside the mixer. Particular care has been taken in the design of levers and controls so as to put everything in convenient and comfortable reach of the operator. The aggregate scale and the asphalt scale, with its telltale dial, are mounted in a steel box in such a position and of such height that the box man views them without moving his head when he is pulling the levers. An electric light is permanently installed above the mixerman on the ceiling of the control deck to illuminate the dials. Electric switches to control all motors are mounted in a steel cabinet on the control deck.

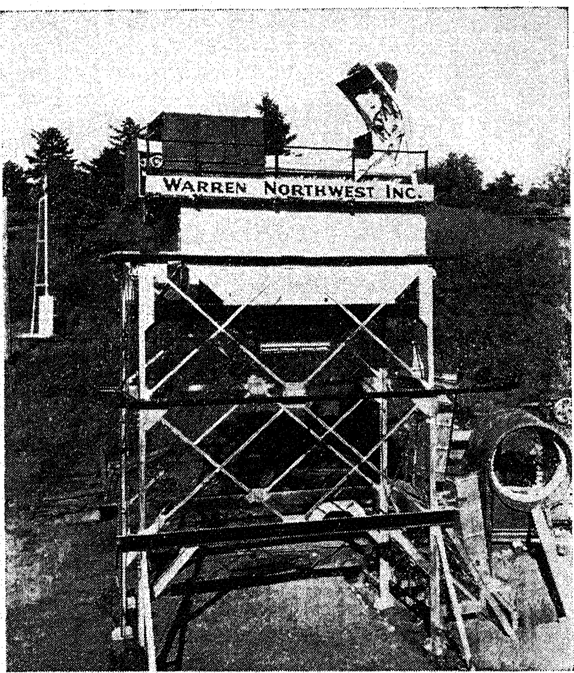


Fig. 3. Unit "A" nearly erected.

Piping.—All piping within the plant itself is permanently installed so it does not have to be torn out and reinstalled when the plant is moved.

Tower.—The tower has been fairly well described in the paragraph headed "Erection" and will be further discussed under details of construction so will not be discussed here.

Part Played by Arc Welding.—In the preceding pages we have given a brief description of the plant as a whole, and will here attempt

to show how arc welding made it possible to build the plant within the strict limitations outlined above.

Time Factor.—One of the very important advantages gained through arc welding was saving of time required for design and construction.

In the Spring of 1937 when we conceived the idea of building a truly portable or "Mobile" paving plant, we had just been awarded a large road surfacing contract, the construction of which was to start as soon as possible. A hurried layout of the entire plant was made and the various essential departures from conventional design were indicated thereon. The layout was discussed with local jobbing shops to see if it would be possible to get the necessary structural elements fabricated in the time allotted. We were advised that if details were submitted without delay and welding would be specified throughout, that it would be possible to meet our schedules, otherwise there would be considerable delay.

We worked day and night on drawings and were able to complete them rapidly because of simplified details allowed through arc welding practice. Due to the flexibility of design allowed through arc welding and the feasibility of making changes without undue expense, we felt safe in submitting certain details to the shop before subsequent details had been worked out. As a result, fabrication of the steel started immediately on completion of the first detailed drawing and subsequent drawings were never more than several days ahead of fabrication. Obviously this procedure would have been very expensive if riveted practice had been adhered to, partially because of the number of holes that would have been drilled in completed steel, to provide for attachment of machinery items and other mechanisms.

The steel tower for Unit A was delivered in less than three weeks from the time the original detail drawing was submitted to the shop and the hopper, which was started one week later than the tower, was completed at the same time. The mixer platform with overflow bins and superstructure (Unit B) was delivered one week later. No thought was given to the drier until several weeks after the bin and tower had been delivered but when its design was finally decided upon, it was built in less than three weeks.

Immediately after delivery of the steel frames for Unit A and Unit B from the jobbing shops, our own shop proceeded to install all the machinery items, levers, scales, etc. The minutest details for the mounting of these machinery items were worked out on paper, frequently a matter of mere hours ahead of the shop, and it was during this part of the work that the many time saving advantages of welding technic made themselves manifest to an extreme degree.

Only eight weeks elapsed from the time the first steel details went into the fabricating shop until the plant was rolling on its own wheels to its first job which was located near Forest Grove, Ore., about 30 miles from the shop. We have been definitely advised by the fabricating shop, that did the greater part of the work, that had it not been for arc welding, it would have taken at least twice as long to complete their part of the work. In addition to this, we know from our own experience that it would have taken us twice as long to assemble the

various units into a complete plant without the art of welding and the cost of this work would have been far above the actual cost experienced.

Weight Factor.—The second major factor, wherein we are indebted to arc welding, was the ability to save weight and thereby stay within the load limits allowed for vehicles on the highways of Oregon, Washington and Idaho, the three states in which the plant was built to operate.

Under the heading of transportation, we have pointed out the maximum allowable weight limits, in general. To be more specific, the particular limitations with which we were concerned for the three units built, were as follows:

For Unit A and Unit C. Total gross weight of the combination of any three-axle trailer and tractor truck in Idaho, 50,000 lbs.

For Unit B. Maximum load per axle of two-axle trailer in Washington, 12,000 lbs.

The Oregon and Washington limitations for Units A and C are slightly more liberal than the limit given for Idaho. Similarly the Idaho and Oregon limitations for a trailer the type of Unit B are slightly more liberal than Washington, but of course, it is the minimums with which we are concerned. In connection with the above limits, particularly as applied to Units A and C, we have the practical requirement, under all conditions, of having approximately 30 per cent of the total gross load, applied on the driving axle of the tractor truck. Generally accepted practice demands this percentage for two reasons (a) to provide enough traction and (b) to insure against the trailer forcing the truck sideways off the road when going downhill around a curve under a condition of inadequate brakes on the trailer or failure of the driver to apply brakes on the trailer.

The gross weight of Unit A is 28,500 lbs. Deducting this from the allowable 50,000 lbs. we get a total gross weight of the tractor truck amounting to 21,500 lbs. of which our truck carries 8,000 lbs. on the front axle when loaded. This leaves 13,500 lbs. load on the traction axle or a total of 27 per cent. From these figures, it is apparent that we are unable, even with our all welded design, to load the tractor truck quite to the minimum safe requirement, when transporting the equipment in the State of Idaho.

Any accepted ratio of weights between welded and riveted structures will clearly show, without further mathematical demonstration, that this plant could not have been built without recourse to arc welding and remain within the weight limits. To further substantiate this statement we submit that the entire plant, insofar as the tower and drier drum is concerned, is shipped on the three trailers illustrated.

It, of course, could not be argued that it would have been impossible to build a similar paving plant without the use of arc welding but we feel that we have conclusively demonstrated that in order to build a plant of like size and capacity, using the standard machinery units required for this capacity, it would have been necessary, without question, to have divided the plant differently so that it could be transported over the highway in four units rather than in three. It is diffi-

cult to surmise what basic design changes would have been necessary to accomplish this result but it can be unreservedly stated that the entire erection and lay-out scheme would have been drastically altered. The result, in this case, would, of course, have been a plant exactly 33% more expensive to transport, which would have immediately reduced it to the status of its competitors.

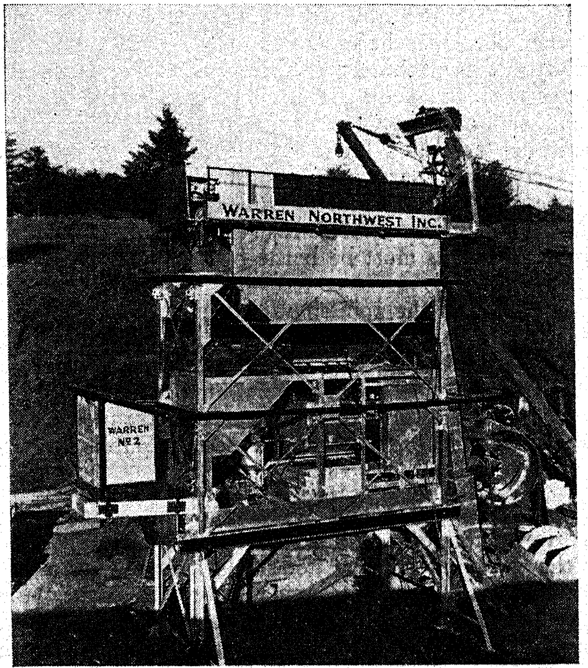


Fig. 4. Tower assembly completely erected.

Cost Factor.—Consideration of cost constitutes the third major reason why arc welding made it possible to build the plant herein described. The cost of equipment is a major item and is usually the chief limitation to the gross amount of work that highway contractors can perform. Great difficulty lies in the fact that the period of usefulness of any unit of equipment is severly limited, first by the short duration of the construction season which, in asphaltic concrete work in the Northwest territory will run on the average from June through November, and second from the fact that the contractor is frequently not fortunate enough to be awarded contracts suited to his equipment with any degree of regularity. It could be estimated therefore that, on the whole, a unit, such as a complete paving plant would not actually operate more than an average of four months per year. Due to these factors and the obvious investment entailed, we are prone to continue the life of equipment over very long periods of time, in spite of obsolescence, in order that the tremendous investment can be written off without reflecting

too severely in the prices bid for contract work. From this, it follows that appropriations for major equipment must necessarily be seriously limited, with the result that repair of existing equipment is usually indicated unless the cost of new equipment can be brought within a fair distance of the cost of repairs.

To describe the details of cost-saving, due to welding, in the structural parts of this plant, would be merely to repeat a frequently written thesis leading to a universally accepted conclusion, so the subject will not be further developed here. Suffice it to say, however, that, in the construction of the machinery described herein, we experienced the usual savings from reduced weight, simplified detail, speedy construction and elimination of expensive patterns for casting. The sum of these savings has been estimated for us by the shop at approximately 40% on the fabricated steel parts of this machine which does not seem excessive in view of the fact that machines of this nature are necessily largely custom built with a result that the cost of templates, patterns, engineering and details must be borne by a comparatively small number of units.

In consideration of the points outlined immediately above, we point out again that this plant would have not been built had it not been for the advent of arc welding, and the industry would thus have been deprived of what we feel to be a very important advance. It is not long before profits accruing to industry from technological advancement, automatically accrue to the public, so the public, at large, surely will share in the advantage gained.

Details of Construction and Welding Details.—In other parts of this report we have given a general description of the plant as a whole, including the major machinery items which were assembled and installed to make up a complete paving plant. These machinery items are of extreme importance in the design of the plant, as it is to give these items ability to function with maximum efficiency that the rest of the plant was designed around them. However, machinery items will not be considered in this section because they were purchased complete or taken from other paving plants and were not designed by the writer. The items which we will here discuss and which were designed and fabricated for this specific plant, are the steel tower and large hopper of Unit A, the mixer platform of Unit B and the drier complete with subframe of Unit C. These items are of all-welded construction and due to their unique design, they alone are responsible for the difference between this paving plant and the prior art.

Tower for Unit A.—The tower, as previously mentioned, is made up of three sections. The top section slides down within the middle section and then both top and middle sections slide down inside the bottom section. Thus all three sections are nested one within the other and the whole surrounding the bin, when Unit A is ready to move on the road.

The lower columns are of 5″ x 5″ x ½″ angles, the columns for the middle section are 4″ x 4″ x ⅜″ angles and the top section columns are 4″ x 4″ x 5/16″ angle. In view of the fact that horizontal cross bracing is not provided until after the hopper is up, and to provide

rigidity against skewing during the erection operation, a peculiar design has been resorted to. We refer to the fact that the horizontal cross members, instead of being channels as might usually be expected, are made of 4″ x 4″ heavy H section with webs in the horizontal plane instead of in the vertical plane. These beams project beyond the tower legs, where they are welded to heavy gusset plates placed in the horizontal plan. These gusset plates cannot be inside the tower because of the collapsible feature which necessitates having the inside entirely free of encumbrances. This construction resists the tendency the tower might have to skew into a diamond shape (as viewed in the horizontal plane) which would of course make raising of the hopper difficult or impossible. It also gives the tower sections enough rigidity to be able to stand up under the rough treatment of transportation and erection, during which time they are not stable structures.

Diagonal bracing for side and end panels is provided by flat bars which were used because of the necessity of having a thin section in the vertical plane to offer the least possible obstruction when one section slides within another. The gusset plates to which these diagonals are welded, are of good size to provide rigidity but continuous welds along their edges were not required to develop their full strength. In order to eliminate all obstructions that would make erection difficult, the gussets are butt welded to the leg angles and the diagonals are butt welded to the gussets. The difficult details that would have been involved in attempting to achieve this result without the use of arc welding, need not be described for it follows without argument that to obtain this result, the cost would have competely discouraged the attempt.

The weight of the tower complete including outriggers and elevator tail shaft assembly is 6,500 lbs. Our estimated weight of a comparable tower of riveted construction was about 7,905 lbs. or an increase of about 22% above the weight of the welded tower. The riveted alternate design investigated here calls for the use of double countersunk rivets and filler plates running the full length of the leg angles, in order that gusset plates would not form objectionable projections. See table below for data on weight.

Welded Construction vs. Riveted Construction on Tower

Actual Weight—Welded Construction*		6,500 lb.
Add for riveted construction:		
Overlap of gussets and filler plates		
Bottom frame ($\frac{3}{16}$″ gussets)		
8 pl $\frac{3}{16}$ x 4½″ x 8′–1″ @ 2.7 lb.	175 lb.	
Middle frame ($\frac{3}{16}$″ gussets)		
8 pl $\frac{3}{16}$ x 3½″ x 9′–0″ @ 2.31 lb.	167 lb.	
Top frame ($\frac{5}{16}$″ gussets)		
8 pl $\frac{3}{16}$ x 3½″ x 9′–0″ @ 3.72 lb.	268 lb.	
Clips, etc. Say 10% of 6500 lb.	650 lb.	
292 Rivets @ ½ lb.	145 lb.	1,405 lb.
Estimated Weight—Riveted Construction*		7,905 lb.

Percent Weight Saving Due to Welded Construction: $\frac{1,405}{6,500} = 21.6\%$

*Including projection for front pony support.

Hopper for Unit A.—The large hopper at the top of the tower is of all welded construction. It is made of 3/16" plate in order to save weight, (usual practice calls for 1/4" plate) and is strengthened where necessary by welded ribs to be described later. The weight of the hopper and the material it contains, is supported by two 10" channels which are bolted to wing plates, butt-welded to the edge of the tower leg angles. Six 3/4" bolts are required to develop the stress at each corner but no special design was deemed necessary to develop this stress in the weld between the wing plates and the tower legs.

The hopper is divided into four separate bins by means of partition plates, the upper four feet of which is hingedly connected to the lower part to make room for the screen to be transported within the bin. To support each partition during operation, the hinged upper portion is bolted to fins which are welded to the hopper side. In order to give added strength to these fins and, at the same time, prevent distortion of the bin sides, a reinforcing detail was resorted to.

We point to the obvious expense that would have been entailed to flange, punch, countersink and rivet all the small plates as opposed to the relatively small expense of chain welding them in place.

An additional complication in the hopper, is the presence of three inclined overflow chutes which run from each of three bins respectively down the side of the hopper, through the partitions to discharge at the end of the hopper into a common overflow bin. (See Fig. 4). Due to the complicated intersections that were involved in carrying out this detail, the shop found it actually cheaper to build the bin partitions complete with the fin reinforcements as described above, and then burn out a passage for each of the overflow chutes. With the aid of arc welding, it was a very simple matter to mount the chutes and patch up small errors in the cut. Had it not been for arc welding, the expensive lay-out work alone on these details, would have been a factor out of all proportion to the weight of material involved.

There is a total of 425 lin. ft. of welding in the hopper in which 85 lbs. of rod was used. The hopper is 7'0" wide, 15'0" long, and 8'4" deep. Its net weight is 6,800 lbs. Following table shows weight comparisons, riveted and welded.

Welded Construction vs. Riveted Construction on Hopper

Actual Weight—Welded Construction		6,800 lb.
Add for riveted construction:		
Replacement of 425 lin. ft. of weld with 425' of 2 1/4" flange in 3/16" plate at 1.43 lbs.	610 lb.	
1700 1/2" rivets at .09 lb.	153 lb.	763 lb.
Calculated Wt.—Riveted Construction		7,563 lb.

Percent Weight Saved Due to Welded Construction: $\frac{763}{6,800} = 11.2\%$

Mixer Platform, Unit B.—Because of the heavy equipment supported by the mixer platform, and the dynamic stresses induced in it by a 100 HP engine driving the mixer at slow speed with tremendous torque, particular attention was paid to this design of the beams, bracing

and connections of this unit. The frame is 6′4″ wide and 23′10″ long. It is made on the same principle as trailer with goose neck frame and is, in fact, a stable trailer when in transit. It was necessary to provide the customary joint about 5′ back from the front end of the frame to give clearance for steerage to the front pony. The shear at the point of intersection between the yoke beam and the main beam happened to be nearly the maximum for the whole frame, so great care had to be exercised in the design of the joint. At first it appeared that a riveted joint would have to be resorted to, using heavy fish plates to connect the two members. However, after considerable study, a welded joint was designed.

Had it not been for our faith in the dependability and economy of welding, we would surely have riveted this important joint in accordance with the usual precedent.

The main frame is composed of two 15″-50 lb. channels, 18′4″ long. The front, or yoke beams are 10″-15.3 lb. channels 7′6″ long with 3/8″ x 10″ cover plates welded to the outstanding legs to form box sections. The 10″ channels rest on top of the 15″ channels and overlap for a distance of 2′. The two sections are welded all around with a 3/8″ fillet. Also a heavy gusset plate is butt welded to the end of the 15″ channel and double lap welded to the 10″ channel. In addition a 1/2″ x 4″ strap was put on each side running from the top of the 10″ channel to the bottom of the 15″ channel. A full fillet weld was run on each side of each strap. To our entire satisfaction this platform has been mounted on its wheels and has been run nearly 500 miles over all kinds of highways without sign of failure.

The mixer platform weight 3,450 lbs. and 40 lbs. of rod was used in this fabrication.

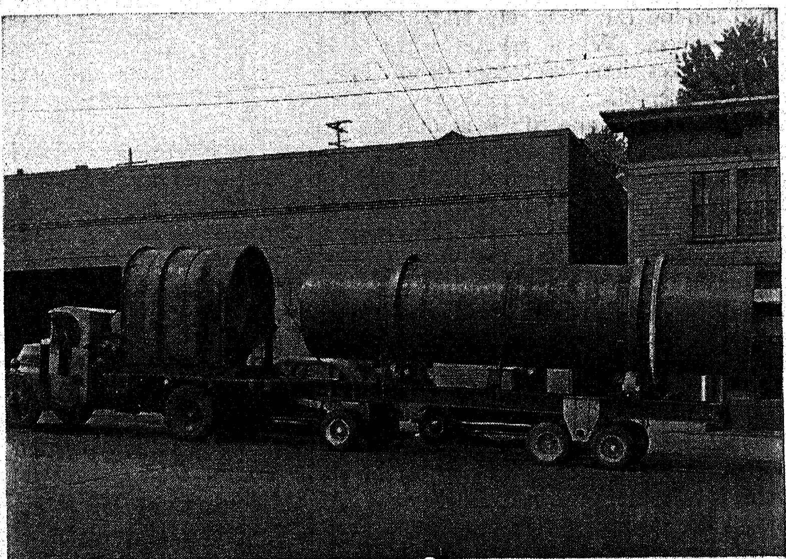


Fig. 5. Drier and combustion furnace in transit.

Drier.—The drum of the drier is 72″ in diameter by 26′0″ long, and is made of 5/16″ plate in four courses. Both the longitudinal and girth seams are butt joints, welded both outside and inside. We find this cheaper than beveling the plates and at the same time we were able to get full penetration. The shell has to be absolutely true in diameter and also straight in order that it will run true. Therefore particular care was used in rolling each course to get a true cylinder. Then to get the shell straight throughout its entire length, a 30 ft. railroad rail was blocked up at each end and the four courses were hung on this rail. After tacking each course to the next one at one point, all the courses were rotated 90° and tacked again. This was continued until the complete shell was tacked together at the four quarter points. This of course, refers to the girth seams only, as the longitudinal seam of each course was completely welded after rolling. After tacking at the quarter points, the shell was checked and found to be straight. Care was then used in welding the girth seams to avoid distortion. When the shell was finished a 5/16″ plate head was welded to the feed end. This head has a circular opening in the center just large enough for the feed chute to project into the drum. A corner weld was used in welding the head to the shell.

The drum is supported by two tires which were made from 2″ x 6″ steel bars. Extreme care was used in rolling the tires to get them true to diameter. After rolling, the ends of the tires were beveled to a 45° opening and welded full. Many passes were made with a 1/4″ rod to make these welds. The welds were built up 1/4″ higher than the outside face of the tire and subsequently trimmed. Shrinkage in the welds pulled the tires slightly out of round, so by heating them at the welds and using a jack, they were forced back to a true circle. When the tires were finished they were put in a boring mill and machine finished around the periphery and the one face which bears against the thrust wheel. When machined the tires are 84″ outside diameter, which makes them large enough to allow a 4″ space between the shell and the tire. This space is needed to keep the heat of the shell away from the tires. Each tire is mounted on ten adjustable brackets. The brackets, which are heavy forgings, are welded to a reinforcing band which goes around the shell under each tire. These reinforcing bands are of 5/16″ plate, 22″ wide which were chain welded to the shell with welds 2″ long at 8″ intervals. The purpose of these reinforcing bands is to prevent the tire brackets from making flat spots on the shell.

Inside the shell are 8″ channel flights at 18″ centers. These flights are bolted to angle lugs, which in turn are welded to the shell. Bolts are used so that, as new flights are required, they can be quickly installed.

The tires roll on heavy trunnions which have 1″ thick welded steel tires shrunk on the rims.

The drum is driven by a cast iron sprocket which is bolted to an angle-iron ring which is welded to the shell. At the feed end of the drum is a housing made of 3/16″ plate. A feed chute is welded to the end of the housing projecting into the drum and a hopper is mounted at the upper end of the chute.

At the discharge end of the drum is another housing with a dis-

charge chute. The furnace projects through the end of this housing. The purpose of these housings is to seal the drum when the dryer is in operation.

The complete drier is mounted on a heavy steel frame. The main members of which are 12″ wide flange beams.

The complete drier is of all welded construction except for the cast iron trunnions, bearing brackets, thrust wheel and sprocket. Two hundred six pounds of rod was used in making up this drier.

We estimate that 10% in weight was saved by welding this drier as compared with riveted construction as indicated by the following data.

Welded Construction vs. Riveted Construction on Drier

Actual weight—Welded Construction (*)			16,102 lb.
Add for riveted construction:			
In Drum:			
Extra steel	632 lb.		
1141 rivets	571 lb.	1,203 lb.	
In Frame:			
Extra steel	475 lb.		
234 rivets	117 lb.	592 lb.	1,795 lb.
Theoretical weight—Riveted Construction (*)			17,897 lb.

$$\text{Percent Weight Saving due to Welded Construction} \;—\; \frac{1{,}795 \text{ lb.}}{17{,}897 \text{ lb.}} = 10.0\%$$

(*) Less castings and tires

Chapter XVIII—Oil Pump Motor Base of Arc Welded Design

By JOHN F. MULLER and G. C. MUNOZ,
Power transmission engineer and general manager, respectively, American Pulley Co., Philadelphia, Pa.

The oil industry has had an extraordinary growth in this country and is today the third largest industry in the country. It represents a capital investment of $6,606,000,000. It produced 1,277,000,000 barrels of oil in 1937 from approximately 350,000 oil wells, and is spending annually about $500,000,000 in drilling new wells at the rate of from 21,000 to 33,000 wells per year.

Most of our oil wells flow for some time due to the gas pressure, but after the pressure in insufficient to cause the well to flow, it is necessary to resort to pumping. The wells in this country may be roughly divided into the following classes:

Flowing Wells	29,000
Gas and Air Lift Wells	1,000
Pumping Wells	320,000
Total	350,000

It is obvious, therefore, that the pumping of oil wells is a vital operation of this immense industry.

During 1937 the average depth of wells drilled was 3,230 feet, with a maximum depth of 6,816 feet and a minimum depth of 510 feet. The problem of pumping oil from the wells is a very difficult one because the pump, of necessity, must be placed near the bottom of the well, requiring a very long piston rod. On every upward stroke of the pump a column of oil and the length of the pistol rod equal to the depth of the well must be raised, and on the down stroke of the pump the weight of the oil plus the weight of the piston rod fall by force of gravity. This causes the belt driving the pump to have a reversal of stresses for each cycle. It is obvious that the lifting and subsequent fall of the column of oil in such deep wells at each stroke of the pump presents a difficult mechanical problem.

These pumps are usually driven by an electric motor or a gas engine, and due to the large speed reduction required, an intermediate countershaft is usually installed, effecting a double speed reduction by using two belts. In other instances, a speed reducing unit with herringbone gears is used.

The product to be described in this report is an oil pump motor base of arc welded steel construction and is shown in Fig. 1.

Description of the Oil Pump Motor Base.—The oil pump motor base consists of a base plate 104″ long supporting a heavy sliding plate 79″ long, on one end of which is welded a tension control motor base which supports the motor driving the unit. At the opposite end

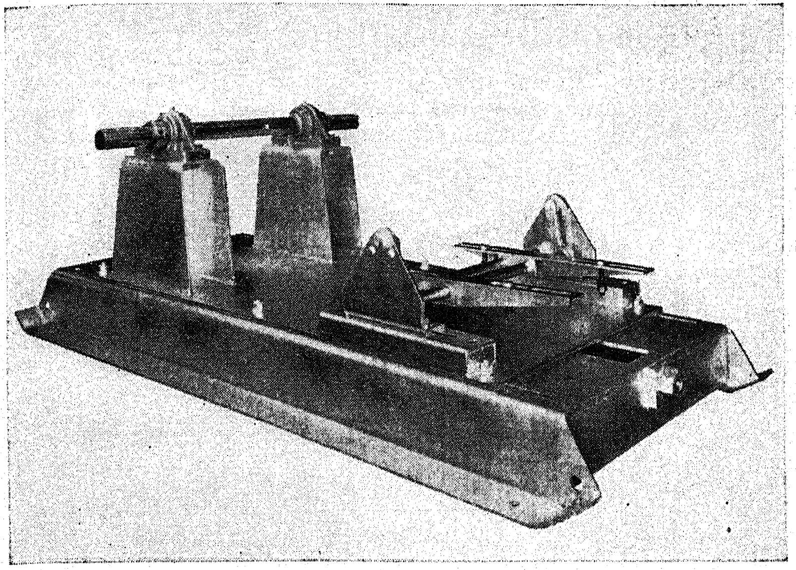


Fig. 1. Arc welded steel oil pump motor base.

of the sliding plate two support brackets are welded, supporting anti-friction bearings for a countershaft. The speed reduction is accomplished by two belt drives—the primary drive from a 12″ diameter motor pulley to a 54″ diameter pulley on the countershaft; the secondary drive from a 20″ diameter pulley on the countershaft to the 144″ diameter bandwheel on the pump crankshaft.

Due to the stress reversals at every cycle of the pump, it is very important that both belts used in the drive be kept at the proper tension at all times. If the motor in this drive were bolted to a stationary base, it would be necessary to have quite a long belt driving the countershaft, but with this unit it is possible to have a very short center drive by mounting the motor on a tension control motor base.

Literally it would be impossible by any manual operation to control belt tension as accurately as does the tension control motor base. It utilizes a force known as reaction torque, which is inherent in every electrical motor and which tends to make the frame of the motor turn in a direction opposite to that of the rotor. In any electric motor this force operates as naturally and surely as your pulse rate increases during strenuous exercise.

The force of this torque varies as the load on the motor is varied and in exact ratio to the horsepower delivered. Therefore, by placing the motor in a cradle that is free to move through a limited arc, this force is harnessed to serve a useful purpose. The motor is almost in balance over the pivot point of the cradle, so the effects of gravity are minimized and at "no load" the drive operates with relatively low-belt tension. But as the load is increased, torque asserts itself, swinging the motor away from the driven pulley, so that the belt is tightened

and the correct tension for the heavy load is automatically provided. As the load is reduced, the motor returns to the proper position to provide correct belt tension. Fig. 2 illustrates the function of the tension control motor base quite clearly.

The important function of adjustment to take up belt stretch is accomplished for the primary drive by means of two adjustment screws on the tension control motor base, marked "7" in Fig. 3.

As a belt 95 feet long is required for the secondary drive, liberal adjustment must be provided to take up belt stretch. This take-up is

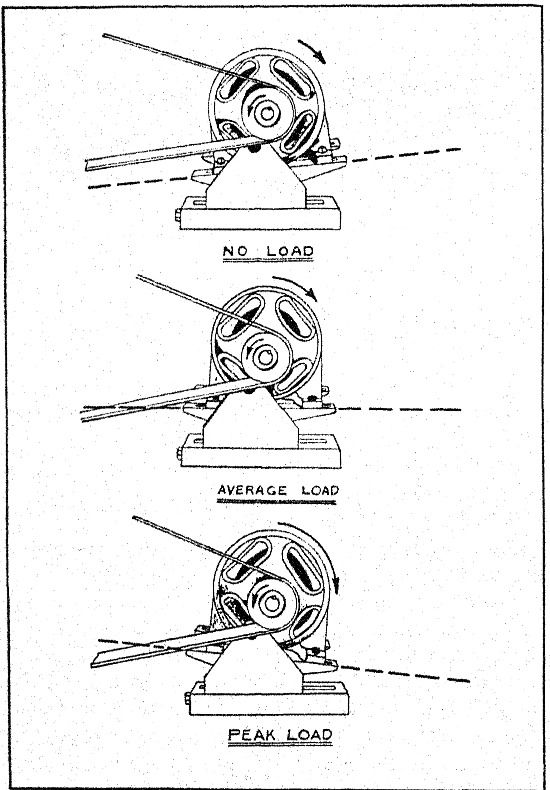


Fig. 2. Diagrammatic sketch illustrating function of tension control motor base.

accomplished on this unit by moving the sliding plate backward on the base plate with the adjustment screw (Part No. 3 shown in Fig. 3). Sixteen inches of adjustment are available for the take-up of the stretch of the secondary belt.

Fig. 4, (Page 1187), shows a detailed design of the base plate (Part No. 1), which consists of a 7/16" thick formed steel plate to which are arc welded bent plates, one at each end, two intermediate cross diaphragms, and two diagonal diaphragms. The top of the base plate has seven slots cut with a gas torch and finished by grinding. The slots are

used in the adjustment of the sliding plate which is bolted on top. To the bent plate at one end of the base plate is arc welded a steel block 4″ x 5″ x ¾″. This block has a clearance hole for the 1¾″ diameter adjustment screw.

The four corners of the base plate are bent upward in order to facilitate the skidding of this unit over the ground from one well to another whenever it becomes necessary to move the unit, and holes are provided at the four corners for towing purposes. Each of the two bottom flanges of the base plate is provided with five holes for anchoring the unit to the floor. These holes are punched in a power press.

The sliding plate, (Part No. 2 of Fig. 4), consists of a ⅝″ thick plate 79″ long and 39½″ wide, to one end of which is welded the tension control motor base, (shown in Fig. 5 and Fig. 3), and to the other end of which are arc welded two support brackets (Part 5, Fig. 4), each consisting of two bent plates and a central diaphragm arc welded one to the other. These brackets support two anti-friction pillow blocks for the 2$^{15}/_{16}$″ countershaft.

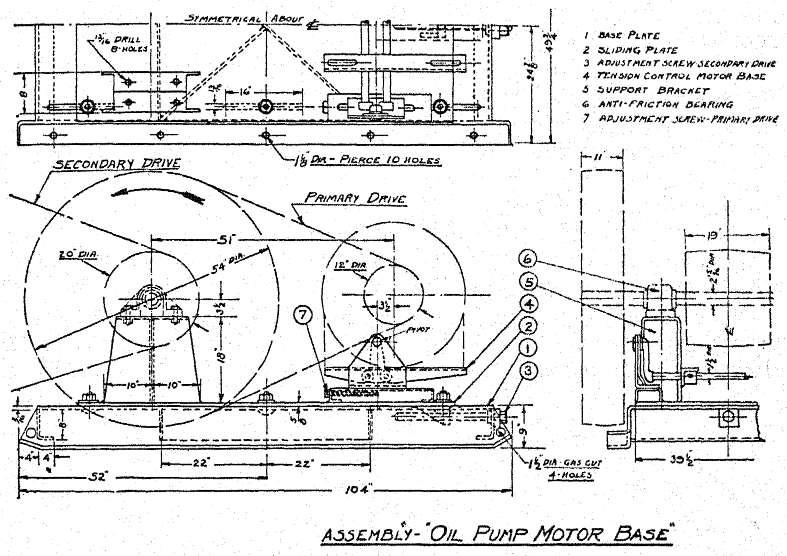


Fig. 3. Assembly of arc welded motor base.

Six holes are drilled in the plate to match the slots in the base plate and are used for bolting the sliding plate to the base plate after belt stretch has been taken up by the adjustment screw. To the under side of the sliding plate is arc welded a 4″ x 4″ x 2″ steel block with a 1¾″ threaded hole through which turns the adjustment screw when taking up the stretch of the secondary belt. Due to the severe strain on this member, it is reinforced by two triangular gussets each $\frac{7}{16}$″ thick, arc welded to both the block and to the sliding plate. These parts are illustrated in phantom view on Part No. 2, Fig. 4.

All of the parts going into the construction of each of the two members which constitute the oil pump motor base are fastened one to the other by means of arc welding, using the shielded arc welding process throughout. Commercial steel plates with a tensile strength of from 55,000 to 65,000 pounds per square inch are used, all with a carbon content of approximately .25. One-quarter inch fillet welds are used on most of the work. After fabrication, all stresses due to the welding are relieved by an annealing operation at 1150 degrees Fahrenheit for two hours, and the parts are then furnace cooled. After this stress-relieving treatment, the members are shot-blasted to remove mill scale and weld splatter.

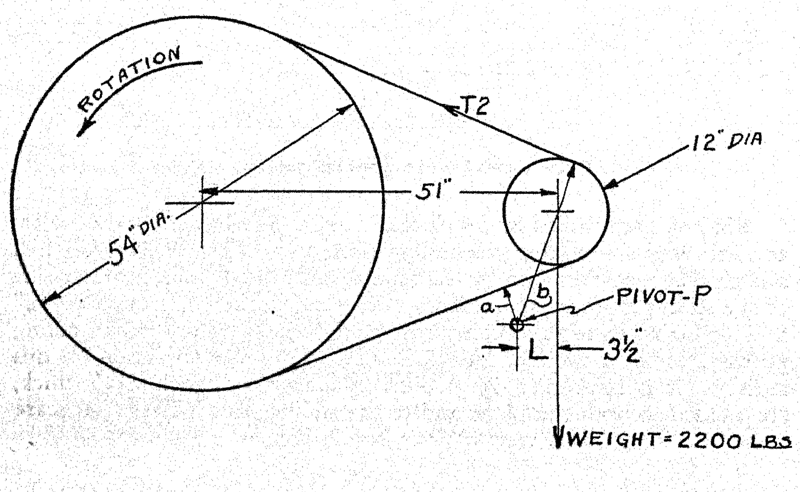
Fig. 4 indicates by cross-hatching the amount of welding used at each joint. Continuous welds are used at all exposed joints to improve appearance, and intermittent welds are used to fasten the diaphragms to the under surface of the base plate wherever the strength of a continuous weld is not needed.

Stress Determinations.—The external forces acting on the various members of the oil pump motor base consist of the total tensions in the primary and secondary belts and the weight of the motor, pulleys and countershaft.

The total tension in both strands of the primary belt are mathematically determined from the following known factors:

(1) 35 Horsepower 585 R.P.M. motor.
(2) Motor weight—2200 pounds (including weight of motor pulley).
(3) Diameter of motor pulley—12″.
(4) Diameter of countershaft pulley—54″.
(5) Lever arm of motor 3½″ from center of pivot of tension control motor base.

In the following calculations T1 is the tension in pounds in the tight or pulling strand of the belt, and T2 is the tension in pounds in the slack strand of the belt.



To determine T1 and T2, two relations between them are required. Taking moments about the pivot point of the tension control motor base, (Fig. 3), marked P in the above diagram, and calling a, b and L the lever arms of T1, T2 and the motor weight respectively:

(1) $aT1 + bT2 - LW = 0.$

A second relation between the tensions is supplied by the fact that the transmitted load is proportional to the product of tension difference and belt speed, as expressed by:

(2) $T1 - T2 = KP$

Where P = maximum horsepower to be transmitted

$$K = \frac{33000 \times 12}{Nd\,\pi} = \frac{33000}{\text{belt speed in ft. per min.}}$$

N = motor R.P.M.

d = diameter of motor pulley in inches

From (1) and (2)

(3) $T1 = \dfrac{LW + bKP}{a + b}$ and (4) $T2 = \dfrac{LW - aKP}{a + b}$

Levers L = 3½″, a = 1″ and b = 16.3″ and maximum horsepower = 70 HP or 100% overload.

Substitute these values in Equations (3) and (4):

$$(3)\ T1 = \frac{LW + bKP}{a + b} = \frac{3.5 \times 2200 + 16.3 \times \left(\dfrac{33000 \times 70}{585 \times 12}\right)}{1 + 16.3} = 1630 \text{ lbs.}$$

$$(4)\ T2 = \frac{LW - aKP}{a + b} = \frac{3.5 \times 2200 - 1 \times \left(\dfrac{33000 \times 70}{585 \times 12}\right)}{1 + 16.3} = 315 \text{ lbs.}$$

Total tension in primary belt T1 + T2 = 1945 lbs.

The total tension in both strands of the secondary belt are determined as follows:

$$\text{R.P.M. of countershaft} = \frac{585 \text{ R.P.M.} \times 12''}{54''} = 130 \text{ R.P.M.}$$

Where 585 R.P.M. is motor speed

12″ = diameter of motor pulley

54″ = diameter of countershaft pulley

The velocity of the secondary belt is determined with reasonable accuracy by using the following well-known empirical formula:

Belt Velocity in feet per minute =

.262 x dia. driving pulley in inches x R.P.M. of driving pulley.

Velocity of secondary belt =

.262 x 20″ x 130 R.P.M. = 680 feet per minute.

Where 20″ is the diameter of the secondary driving pulley on the countershaft and 130 R.P.M. is the speed of the countershaft.

$$\text{Effective belt pull} = \frac{33000 \times 70 \text{ H.P.}}{680 \text{ ft. per min.}} = 3200 \text{ lbs.}$$

(a) $T1 - T2$ = effective belt pull = 3200 lbs.
$T1$ = tension in pulling strand of belt.
$T2$ = tension in slack strand of belt.

(b) $T1/T2$ = ratio of belt tensions assumed as 3.
$T1/T2 = 3.$

(c) $T1 = 3T2.$

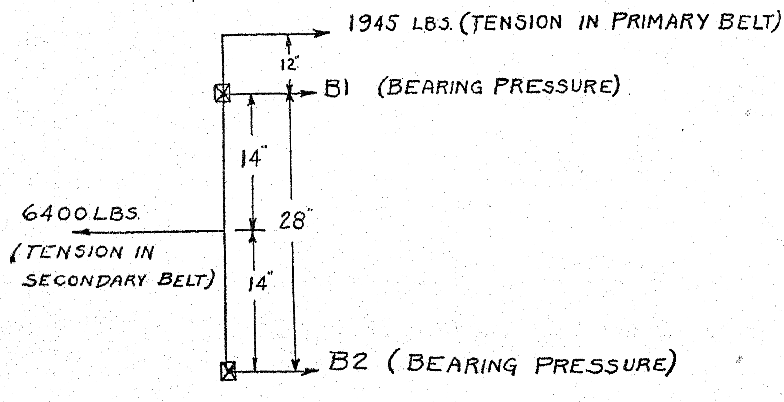
Determine T2 by substituting (c) in (a) $3T2 - T2 = 3200$ lbs.

$$T2 = \frac{3200}{2} = \underline{1600 \text{ lbs.}}$$

Determine T1 by substituting the value of T2 in Equation (c)
$T1 = 3 \times 1600 \text{ lbs.} = \underline{4800 \text{ lbs.}}$

The total belt tension in secondary belt $= T1 + T2 = 4800$ lbs. $+ 1600$ lbs. $=$ 6400 lbs.

Stresses on the countershaft caused by the total tensions in both belts are determined as follows:



B1 = Bearing pressure on countershaft bearing (Part 6 on Fig. 3).
B2 = Bearing pressure on the other countershaft bearing (see sketch above).

To determine B2, take moments about B1 $(B2 \times 28) - (6400 \times 14) - (1945 \times 12) = 0.$

$$B2 = \frac{(6400 \times 14) + (1945 \times 12)}{28}$$

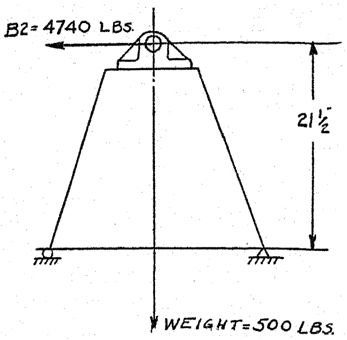
$\underline{B2 = 4740 \text{ lbs.}}$

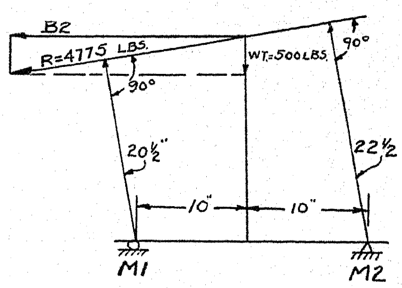
To determine B1, take moments about B2 $(B1 \times 28) - (6400 \times 14) + (1945 \times 40) = 0.$

$$B1 = \frac{(6400 \times 14) - (40 \times 1945)}{28}$$

$\underline{B1 = 425 \text{ lbs.}}$

Since B2 is larger than B1, the support brackets will be designed to meet requirements of B2.





Determine resultant of B2 and weight on B2 by graphical solution as indicated in sketch above as R = 4775 lbs.

To determine the stresses at the arc welded connection between the support bracket and the sliding plate.

M1 = stress on left side of support bracket (see sketch above).

M2 = stress on right side of support bracket.

Determine M1 and M2 by moments.

<u>Moments about M1</u>

$$M2 \times 20 = R \times 20.5$$

$$M2 = \frac{4775 \times 20.5}{20} = 4900 \text{ lbs. tension}$$

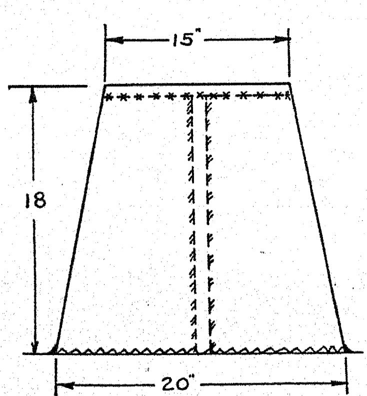
<u>Moments about M2</u>

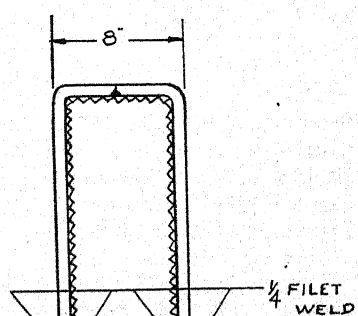
$$M1 \times 20 = 22.5 \times R = 22.5 \times 4775$$

$$M1 = 5380 \text{ lbs. compression}$$

Since the maximum stress on one support bracket is 4900 lbs. tension and 5380 lbs. compression, 5380 lbs. + 4900 lbs. = 10280 lbs. must be withstood by the welding.

As 1″ of ¼″ fillet weld will withstand safely 2000 lbs. in either tension or compression, $\frac{10280}{2000} = 5.14''$ of weld are necessary.





The support bracket is 20″ wide at the base, and while only 5.14″ of 1/4″ fillet weld are required, the entire length is welded to add to the appearance of the unit. Eighty inches of weld hold the support bracket to the sliding plate, which allows a factor of safety of 80/5.14 = 15.6.

In general, it may be stated that the various members of the arc welded oil pump motor base, all of which are attached one to the other by arc welding, have been so designed that there is more than sufficient welding to carry the ordinary stresses and overloads to which the base will be subjected in service, resulting in large factors of safety throughout. This was done because a study of alternate designs indicated that this all-welded construction was by far the most economical way of building this unit, as can be shown by the following comparison in cost of manufacture of the unit described herein with a similar unit built of cast iron.

Cost Estimates

A. Oil Pump Motor Base—(All-steel construction—arc welded)

The estimated cost of the unit is based on the following factors:

1. Labor—80¢ per hour.
2. Power—2¢ per K.W.H.
3. Electrodes—12¢ per lb.
4. Machine efficiency—50%.
5. Steel—2.55¢ per lb.

Items 1 to 4 inclusive are combined so that 1/4″ fillet welds cost 10¢ per foot.

Part No. 1—Base Plate—(Fig. 4, Page 1187)

Steel—1—7/16″ x 54″ x 104″	Wt. 740 lbs.
2—7/16″ x 7 1/2″ x 40 1/8″	Wt. 80 lbs.
2—7/16″ x 11″ x 40 1/8″	Wt. 116 lbs.
1—7/16″ x 7 1/2″ x 59″	Wt. 58 lbs.
2—7/16″ x 7 1/2″ x 29″	Wt. 57 lbs.
1—3/4″ x 4″ x 5″	Wt. 5 lbs.
Total Weight	1,056 lbs.

Steel—1056 lbs. @ .0255	= $26.93
Cutting to size 70 ft. @ 3¢ per ft.	= 2.10
Welding 24 ft. @ 10¢ per ft.	= 2.40
Cut and grind 6 slots—16 x 3/4″	= 1.28
Pierce ten 1 1/8″ dia. holes—	
Set up 60¢	
Labor 20¢	= .80
Drill one hole 1 7/8″ dia.	= .30
Overhead—150% of labor	= 10.32

Total Cost of Part No. 1 .... **$44.13**

Part No. 2—Sliding Plate—(Fig. 4)

Steel—1—5/8" x 39½" x 79"	Wt.	585 lbs.
1—2" x 4" x 4"	Wt.	9.5 lbs.
1—7/16" x 4" x 4"	Wt.	2.1 lbs.
Total Weight		596.6 lbs.

Steel—596.6 lbs. @ .0255	=	$15.21
Cutting—23.5 ft. @ 3¢ per ft.	=	.71
Welding—4 ft. @ 10¢ per ft.	=	.40
Drill six 13/16" dia. holes	=	.40
Drill and tap one hole 1¾" dia.	=	.80
Overhead—150% of labor	=	3.47
Total Cost of Part No. 2		$20.99

Part No. 5—Support Brackets (Two Required)—(Fig. 4)

Steel—1—7/16" x 20" x 44"	Wt.	115 lbs.
1—7/16" x 7⅛" x 17 9/10"	Wt.	16.5 lbs.
Total Weight		131.5 lbs.

Steel—131.5 lbs. @ .0255	=	$3.35
Cutting—15 ft. @ 3¢ per ft.	=	.45
Welding (including welding to Part No. 2)—17 ft. @ 10¢ per ft.	=	1.70
Drill four ¾" dia. holes	=	.40
Overhead—150% of labor	=	3.83
Total Cost per Bracket		$9.73
Total Cost for Two Brackets		$19.46

Part No. 3—Adjustment Screw.

Steel—2¼" dia. x 30" long	Wt.	36 lbs.
36 x 5.5	=	$1.98
Labor—3 hours @ 80¢	=	2.40
Overhead—150% of labor	=	3.60
1—1¾" Hex nut and pin	=	.42
Total Cost of Part No. 3		$8.40

Part No. 4—Tension Control Motor Base—(Fig. 3)

Part No. 4 is a pivoted motor base made completely of arc welded steel construction, the operation of which is described previously.

The shop cost (including overhead and material) of Part No. 4	=	$24.00
Welding of Part No. 4 to Part No. 2—		
6 ft. of ¼" fillet welding @ 10¢ per ft.	=	.60
4 ft. of ¼" butt welding @ 15¢ per ft.	=	.60
Overhead—150% of labor	=	1.80
Total Cost of Part No. 4		$27.00

Total cost of assembled unit shown in Fig. 1, not including motor, pulleys or belts—

Part No. 1	**$ 44.13**
Part No. 2	**20.99**
Part No. 3	**8.40**
Part No. 4	**27.00**
Part No. 5	**19.46**
2—Anti-friction bearings	**40.00**
Countershaft and 2 collars	**7.00**
General Assembly	**6.00**
Total Shop Cost	**$172.98**

B. Oil Pump Motor Base—(Cast iron construction)—(Fig. 6).

(1) Base Plate.—

Pattern cost—$120 (Charge 1/20th)	=	$ 6.00
Rough casting—2140 lbs. @ 6¢ lb.	=	128.40
Machining @ 85¢ per hour	=	18.50
Overhead—150% of labor	=	27.75

Total Cost of Base Plate $180.65

(2) Sliding Plate and Support Brackets.—

Pattern cost—$75 (Charge 1/20th)	=	$ 3.75
Rough casting—1080 lbs. @ 6¢ lb.	=	64.80
Machining @ 85¢ per hour	=	9.35
Overhead—150% of labor	=	14.03

Total Cost of Sliding Plate and Support Brackets........ $88.18

(3) Adjustment Screw.—
Same as used in arc welded Base—Net Cost........ $ 8.40

(4) Tension Control Motor Base.—
Same as used with arc welded Base (See Part No. 4, Fig. 3)
Total Net Cost $27.00

(5) Assembly.—
3 Hours @ 80¢ per hour
plus
Overhead—150% of labor........ = $ 6.00

Total Cost of Assembled Unit Using Cast Iron Parts (not including motor, pulleys or belts).

(1) Base Plate	**$180.65**
(2) Sliding Plate and Support Brackets	**88.18**
(3) Adjustment Screw and Nut	**8.40**
(4) Tension Control Motor Base	**27.00**
(5) 2 Anti-friction Bearings	**40.00**
(6) Countershaft and 2 collars	**7.00**
(7) Assembly	**6.00**
Total Shop Cost	**$357.23**

C. Comments on Estimates.—

Shop Cost of Arc Welded Steel Constructed Oil Pump Motor Base $172.98

Shop Cost of Cast Iron Constructed Oil Pump Motor Base 357.23

Estimated saving per unit of welded steel compared to cast iron..$184.25

Proportionate Cost Saving in Percentage of Cost of Cast Iron Unit .... = 51.6%

Percentage Difference of Weights.—

Weight of Arc Welded Steel Unit .... 2,130 lbs.

Weight of Cast Iron Unit .... 3,560 lbs.

Saving in weight in welded steel unit .... 1,430 lbs.

Saving in Weight as Percentage of the Weight of

$$\textbf{Cast Iron Unit} = \frac{1430}{3560} = \qquad 40.2\%$$

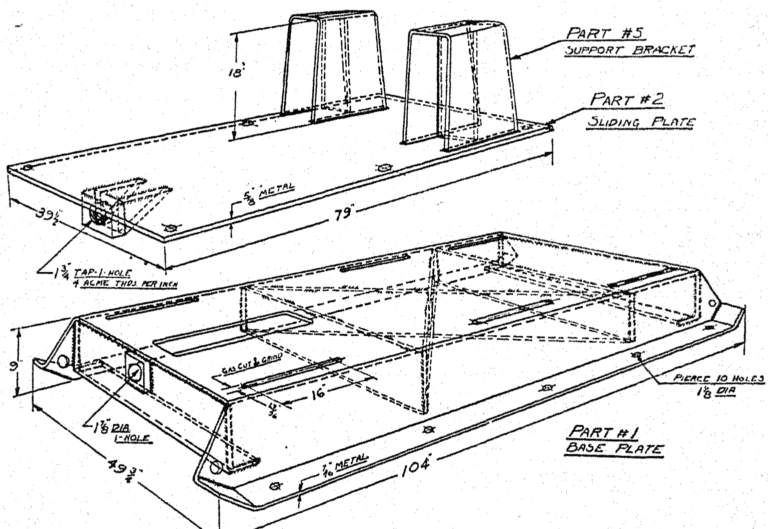


Fig. 4. Detailed design of arc welded motor base.

Conclusions.—No. 1; As the arc welded oil pump motor base described herein is an original design which has been developed recently to correct the difficulties encountered in other types of oil pump drives, it is not possible to compare the cost of this arc welded steel base with that of previous methods of construction, because only one unit (of arc welded construction) has been built to date, which unit has been sent to the mid-continent oil fields for test. However, in the studies sur-

rounding this design an estimate was made of the cost of building this same unit of cast iron, as shown in Paragraph B above. The net result of these two cost estimates indicates that the proportionate cost saving made possible by the arc welded unit in percentage of the cost of the cast iron unit is 51.6%.

The arc welded unit is considered superior to that of cast iron for the following reasons:

1. Lower cost by 51.6%.
2. Lighter weight by 40.2%.
3. Easier to move from one well to another.
4. More pleasing in appearance.
5. Less danger of breakage.
6. Lower freight cost in transporting, by 40%.

No. 2, The gross savings accruing to industry through the general adoption of the oil pump motor base can be determined as follows.

It is first necessary to describe the installation that has been used in the recent past. The motor is mounted on slide rails which are bolted to the floor of the pump house. The primary drive is a long center drive, driving to the countershaft which is fastened to the floor of the pump house. Due to the fact that the countershaft is fastened to the floor, it is necessary to install a belt tightener to take up the stretch of the secondary belt. All of this equipment and the bandwheel operating the oil pump are housed in a corrugated iron building with steel frame and concrete floor.

Comparative estimates are given below of the cost of installing the original equipment outlined above as compared with the new installation using the oil pump motor base. The items in the two installations which are identical, such as motor, pulleys and secondary belt, are not included in the estimates.

The estimates follow:

Original Installation.—

Slide Rails	$ 20.00	
Primary Belt	150.00	
Countershaft and Supports	77.00	
Belt Tightener for Secondary Belt	275.00	
Pump House (extra length due to long centers of primary drive)	100.00	
Total		$622.00

Proposed Installation, Using Oil Pump Motor Base.—

Oil Pump Motor Base, installed	$400.00*	
Primary Belt	60.00	
Total		$460.00
Reduction in Installation Cost per Well by the Use of Oil Pump Motor Base		$162.00

*Attention is called to the difference between the cost of the oil pump motor base, installed, of $400.00 in the estimate and the shop cost of the oil pump motor base outlined in detail previously, which shop cost

totaled $172.98. The reasons for this apparent discrepancy are that to the shop cost of the oil pump motor base must be added the following factors to arrive at the cost of the oil pump motor base, installed:

1. Administrative and selling expenses of manufacturer.
2. Profit of manufacturer.
3. Transportation cost from factory to oil field.
4. Administrative expenses and profit of oil well supply company making the sale.
5. Cost of installation.

After a careful study of statistical data of the oil industry, it was ascertained that approximately 320,000 wells are being pumped today in the United States, but the statistical data did not disclose the number being pumped by electric motors. The field studies made in connection with the development of the oil pump motor base disclosed that in the mid-continent oil field electric motors are used almost exclusively in the pumping of oil wells. The studies made in the Texas oil field disclosed that while some electric motors are used, the majority of the oil wells are pumped by the use of small multiple-cylinder gas engines.

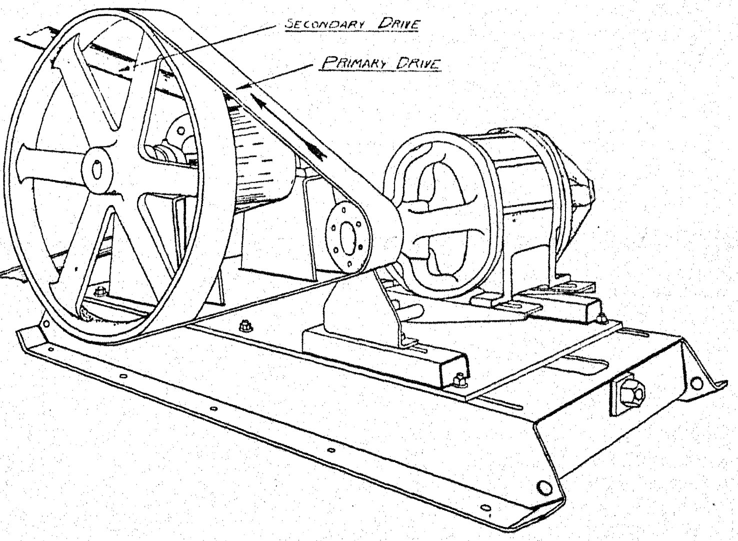


Fig. 5. Tension control motor base, welded to sliding plate.

While in this report the use of the oil pump motor base has been described only in connection with electric motors, it is the opinion of engineers making this study that this unit will also work very efficiently with small multiple-cylinder gas engines of the type used generally in the Texas oil field for pumping oil wells. However, as no actual tests have been made to date using gas engines, the estimate below will include only electric motors.

As definite statistics are not available to determine the exact number of wells being pumped by electric motors, an estimate has been made based on the field data collected on the subject, and it appears reasonable to believe that of the 320,000 wells being pumped in the United States 100,000 are using electric motors. From these figures it is easy to determine that the gross savings accruing to industry (in the United States) through the general adoption of the oil pump motor base would be 162 x 100,000 = \$16,200,000.

No. 3; The increased service life of the transmission equipment for pumping oil by the introduction of the oil pump motor base may be described as follows:

a. Due to the functioning of the tension control motor base, (See Fig. 5), described in preceding pages, the average belt tension is greatly reduced and this, in turn, increases the service life of both the motor bearings and the countershaft bearings by approximately 20%.

b. The reduced average belt tension in the primary drive increases the life of the primary belt by approximately 20%.

c. By the elimination of the belt tightener, which thereby eliminates the injurious double flexing of the secondary belt, and through the 16" take-up provided in the oil pump motor base for tightening the secondary belt while the unit is in operation, the life of the secondary belt is increased by an amount estimated at 30%.

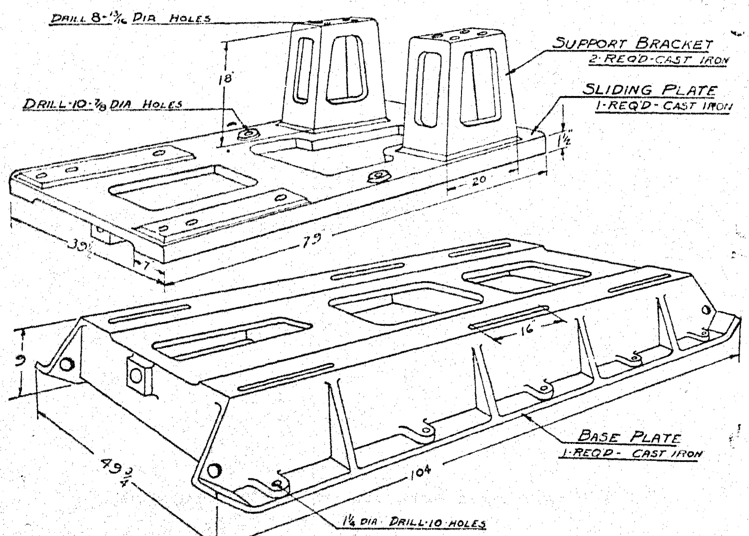


Fig. 6. Oil pump motor base—cast iron construction.

All of these estimated savings have been frequently demonstrated in tests made on tension control motor base installations in other industries in this country, which tests have demonstrated that where tension control motor bases are used, the average belt tension is reduced 50% as compared with other motor mountings.

The increased efficiency, general economy and social advantage provided by the oil pump motor base may be described as follows:

a. The automatic control of belt tension obtained by the installation of the tension control motor base, as explained previously, causes a reduction in power consumption of approximately 4%. This 4% economy has been frequently demonstrated in laboratory tests made at Swarthmore College and tests made of actual motor base installations in various industries throughout the country.

b. One of the primary objectives in the design of the oil pump motor base was the elimination of the belt tightener in common use in the secondary drive of older types of oil pump installations. The objections to the belt tightener are as follows:

(1) The injurious double flexing of the belt, which reduces its life.
(2) The increased consumption of power caused by this double flexing and by the frictional resistance in the bearings of the belt tightener.
(3) The high maintenance cost of the belt tightener.

The elimination of these objections by the installation of the oil pump motor base is one of the principal claims for the increased efficiency, general economy and social advantage of the oil pump motor base.

During the past 150 years the United States has experienced the most extraordinary development in the history of mankind. In this relatively short period our annual national income has increased from four hundred million dollars to eighty billion dollars, and our national wealth from five hundred million dollars to about three hundred seventy-five billion dollars, with the result that the American standard of living has become the highest yet achieved by the human race.

Engineers, inventors, research laboratories are constantly finding new and better ways of accomplishing the work of the world, and gradually through the free play of our competitive system, these improvements raise our standard of living to new and higher levels.

During the past few years one of the outstanding achievements with great social implications has been the development of the art of arc welding. This new industrial process is used in shipbuilding, in the erection of skyscrapers, in the laying of pipe lines, and in countless industrial operations. The rapid substitution of arc welded steel frames for industrial machinery in place of cast iron or cast steel is a recent development of importance.

It is not surprising, therefore, that when a careful study was made by the engineers designing the oil pump motor base, they concluded that of all the different methods by which this unit could be built, the arc welded steel construction was the most economical, the most pleasing in appearance, and embodied a maximum of strength with a minimum of weight to withstand the hard work in the oil fields.

Chapter XIX—Manufacture of Composite Metals by Carbon Arc Welding

By Robert E. Kinkead,
Consulting engineer, welding, Cleveland, Ohio.

Practically since man first began to use materials, he has employed them in certain combinations to accomplish desired results. In his first shelter, he used crude logs or poles for supports, dried mud and grass for the walls and a similar composition for the roof. Later, certain refinements appeared in the form of hewn or shaped timbers for frame work, planed lumber for walls and roof, etc.

Today, the use of composite materials is reflected in many and varied forms. Galvanized wire, pipe and sheets combine the strength and low-cost of steel with the corrosion resistance of zinc. Steel is coated with glass, rubber, copper, brass, paint, lacquer, alloys for hard facing, etc. —all for the purpose of increasing utility and serviceability.

The actuating motive in use of composite metals is usually one of reducing the initial cost or the cost of use. Thus, copper-clad steel wire for railway signal bonds last ten to twenty times as long as pure copper bonds of the same initial cost, on account of the resistance of the steel

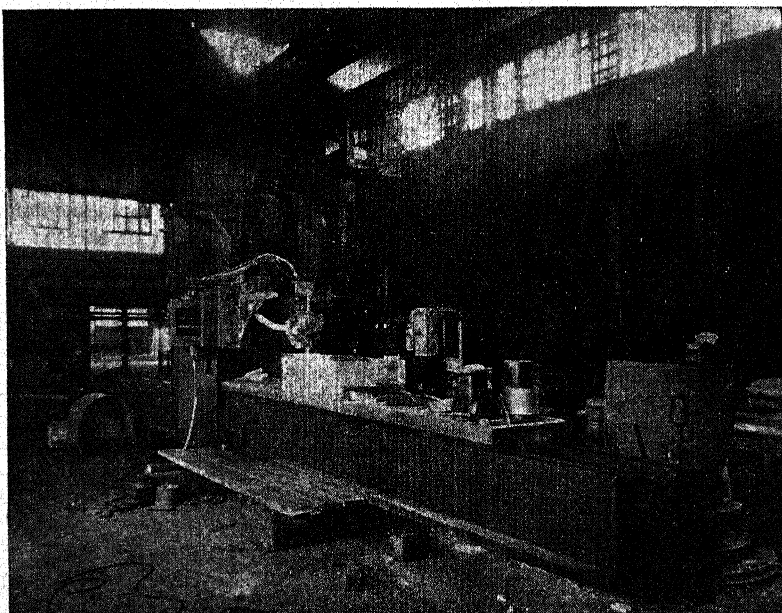


Fig. 1. Experimental equipment used for making composite metals by carbon arc welding.

core to destruction by vibration. Nickel-clad steel used for making vessels which handle food products cost about one half as much as solid nickel plate for the same purpose. The composite has greater strength and, since only one side can possibly come in contact with food, serves the purpose exactly as well as solid nickel plate. No one will knowingly pay $1,000 for solid nickel plate when $500 spent for nickel-clad steel will do the job equally well.

The chromium nickel alloys which have been developed in recent years have found many uses. The 18% chromium with 8% nickel specification with additions of possibly molybdenum, columbium, or titanium, comprise the most popular group of stainless steels at the present time. The use of these almost noble metals is inhibited by the high price for which they must be sold. At $580 per ton base price,

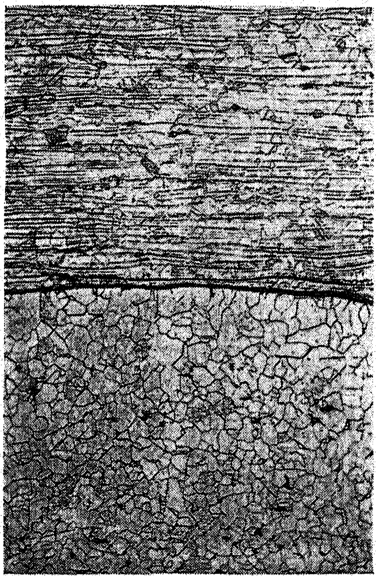


Fig. 2. Completely processed stainless clad steel, 14 gauge sheets. Structure of 18-8 Mo clad sheet. In the photograph the dark bond may appear to be a separation of the two metals, but such is not the case. 100 X. Etchants: Electrolytic chromic acid and 5% nital.

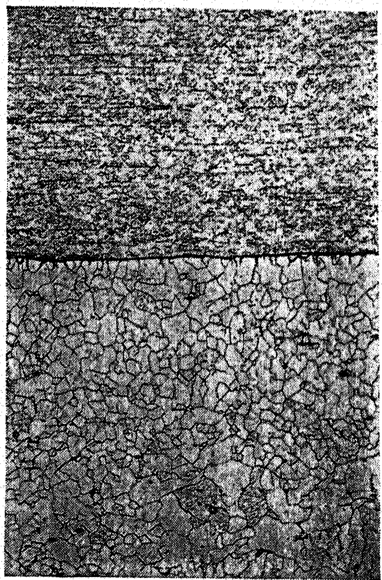


Fig. 3. Completely processed stainless clad steel, 14 gauge sheets. Structure of 18-8 Cb clad sheet. 100 X. Etchants: Electrolytic chromic acid and 5% nital.

18-8 costs roughly 14 times as much as carbon steel. For about half the known uses, low carbon steel with a properly applied cladding of 18-8 would serve the purpose just as well as solid stainless. The price might be half as much for the composite material as for the solid stainless. With a 1937 production of 75,851 tons of finished stainless and heat resisting alloys, having an aggregate value of about $60,000,000, the desirability of composite material is obvious.

While the advantages of composites of low carbon steel and very expensive metals is striking, the economies of composite metals are by no means restricted by such cases. Thus, one of the serious problems which has been encountered in the design and construction of welded steel machinery has been a lack of low cost composite metals. Machined surfaces on low and medium carbon steel are expensive as compared with machine work on steel having .40% carbon, and it is a fact that lubrication is difficult and wear unsatisfactory for rapidly moving parts made of low carbon steel. Building up such surfaces by manual or even automatic arc welding machines is, in many cases, prohibitively expensive. On the other hand, if the parts are made of steel having the machining and wearing qualities of .40% carbon or more, it becomes necessary to preheat the machinery part in the welding operation to prevent it from cooling rapidly and cracking.

Fig. 4. Completely processed stainless clad steel, 14 gauge sheets. Micro-structure of 12% chromium clad steel sheet, showing clad bond and base metal. The clad structure (top) consists of ferrite and carbides and is typical of regular 12% chromium. The structure of the plain carbon base metal is normal. The bond consists of small ferrite grains with a large number of carbides. 100 X. Etchants: Electrolytic chromic acid and 5% nital.

A notable example of this limitation in the building of welded steel machinery parts is the problem of making welded steel gear blanks. The rim needs to be .40% carbon steel or above to have the gear tooth cutting operation successful. The remainder of the gear blank may be medium carbon steel. The job of handling the welded type of gear blank and welding it while hot is so difficult that most manufacturers prefer to buy cast steel blanks. If a line of bar stock were available from the steel mills with say 50% of the thickness .40% to .50% carbon and the remainder in the .15% to .25% range, most manufac-

turers would make their own gear blanks by welding. The rim would be formed hot with the higher carbon on the outside. The assembly of the welded steel gear blank could then be made by welding on the low carbon side without preheating.

The above described composite would also be useful in welded steel machinery for guides, ways on planers, and in many other places on the machine where a surface is machined and subjected to wear.

The Need for a New Method of Making Composite Metal.—When composite metals are to be fabricated, their usefulness is often a function of the quality of the bond between the component parts of the composite. Unless the bond is perfect, the metals separate in fabrication. Thus, plating alone is used *after* the metal has been formed and

Fig. 5. Completely processed stainless clad steel, 14 gauge sheets. Micro-structure of 17% chromium clad steel sheet. The clad consists of ferrite and carbides, and with the exception of the laminated condition, is comparable to solid 17% chromium. The structure of the base metal (at bottom) is normal. The dark etching bond is similar to the bond of Fig. 3 and is composed of ferrite and a large number of carbides. Etchants: Electrolytic chromic acid and 5% nital.

all of the cold work completed on it. The bond is one of adhesion, not cohesion as in a weld. To get cohesion in a plated composite it must be hot rolled.

A further necessity is that the composite have a uniform and entirely complete bond between the components. Thus, even though 98% of the area of contact between the components is perfectly bonded by cohesion, but the remaining 2% of the area is held only by adhesion, the composite will be commercially unacceptable. Failure will occur when the composite is formed with the surface component in compression, or the defects will show up as blistering in service where the com-

posite material is subjected to heat. A skillet made of a composite of carbon steel and stainless for the inside serves the purpose well if the bond is perfect and complete. But if the bond is not perfect and complete the stainless will blister because it has about three times the coefficient of expansion and contraction of carbon steel. The point is well illustrated also in the case of stainless steel-lined oil refinery vessels. While they give a satisfactory life in consideration of their cost, they fail by blistering between welds long before the lining itself is appreciably corroded. No low cost composite metal meeting these requirements has heretofore been available, in spite of these obvious needs.

Fig. 6. Completely processed 17% chromium clad steel, 14 gauge sheet. Structure of clad (top) is typical of the structure of 27% chromium. The bond is structureless. The grain growth in the open hearth steel was confined to the zone next to the bond. 100 X. Etchants: Electrolytic chromic acid and 5% nital.

The requirement that the bond in composite metals be good for 100% the area of contact is the first and most important necessity. The second need is that the composite shall be made by low cost methods so that its manufacture and sale may be carried out to yield a profit to the maker.

Making Composite Metals in the Steel Producing Plant.—The necessity for making the composites at low cost immediately indicates that the metal should be operated on as early in the basic process of manufacture as possible. Steel is made, rolled and processed by the most expensive machinery in order to handle it on a mass production basis and produce it at a cost which promotes its universal use. The conclusion cannot be escaped that the time to make the composite is while

the metal is in the ingot or slab or, in some cases, the billet form. If the metal is made composite here, it goes through all of the subsequent rolling and processing equipment which can handle it at high speed and low costs.

The contrasting cases of making nickel clad steel and making electroplated copper clad steel, which is subsequently hot rolled, illustrates the point. Nickel clad steel is made by rolling together solid nickel slabs and steel slabs. A one-inch thick nickel slab may be rolled onto a nine-inch thick steel slab. Thus, by working on one square foot of steel 10″ thick, 80 square feet of 10% nickel clad steel is obtained when it is rolled down to 1/8″ thickness. On the other hand, plating .013″ of copper on .125″ thick steel for subsequent hot rolling would be entirely prohibitive in cost, because 80 times the area would have to be operated on.

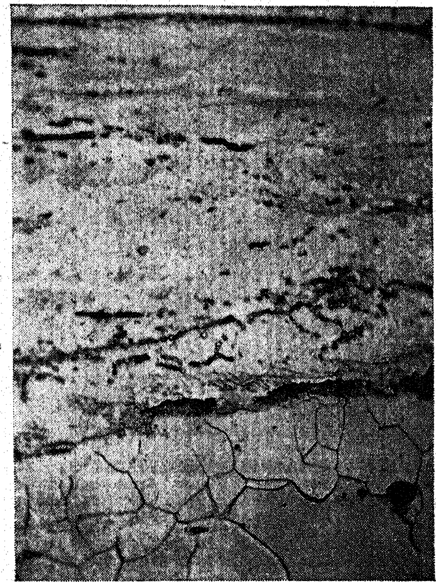


Fig. 7. Micro-structure of semi-processed 18-8 clad steel ½ plate hot rolled. Showing in greater detail the structure where the two metals join. 750 X. Etchants: Electrolytic chromic acid and 5% nital.

The process and equipment hereinafter described is designed to work on ingots, slabs, or billets in the steel producing plant and be further processed by existing equipment.

Composite Metals by Carbon Arc Welding.*—In the steel making process, the metal in the ingot stage represents the lowest cost of the metal in the solid state. Value is added by all of the subsequent operations. It is most desirable, therefore, to make the composite when the metal is in the ingot stage, particularly by the process hereinafter de-

*Patents are pending on process described.

scribed. Considering an ingot of low carbon steel, all that is needed to make it a composite is to add the necessary alloying elements to the metal on the surface to get the desired chemical analysis. This may be readily accomplished by carbon arc welding. It would be a round about and relatively expensive process to coat the surface of the ingot with the alloy desired in the form of a metal wire or rod using the metal electrode arc welding process. Thus, in the making of a composite having an 18-8 stainless surface, in the case of carbon arc welding, it is only necessary to add ferrochrome and nickel with an alloying element cost of about 8¢ per pound of 18-8 produced. Making an 18-8 surface

Fig. 8. Micro-structures of completely processed 18-8 clad steel, 14 gauge sheets. Structure of clad bond and base metal. Heavy grain boundaries in clad near bond indicate carbide precipitation. Structure of base metal is normal. 100 X.

by depositing 18-8 rod and metal arc welding would immediately involve a cost of 50¢ to 60¢ per pound for the stainless steel rod. In the latter case, the alloy is made and reduced to rod form suitable for welding and heavy costs are involved. In the carbon arc method, the stainless steel is made directly on the ingot using the ingot metal itself as the base.

Experimental production of composite metals by carbon arc welding has been carried out over a period of two years. To avoid excessive cost of experimental apparatus, work has been done on slabs where the depth to which the surface alloying extended could be from ½″ to 1″. Large current supplying apparatus would have been required to increase this depth to 2″ or 4″, as would be required on thick ingots for a 20% depth of surface alloy. Such apparatus was not available for experimental purposes.

Fig. 1 shows the experimental equipment used. A Lincoln Tornado Carbon arc head is mounted on the tool carriage of a planer. Motor and

cam arrangement is provided to oscillate the head transversely to the direction of travel of the planer bed. The cam was designed empirically to give uniform distribution of the heat in operation so that uniform depth of penetration of the alloy was the result. The cam turned out to be asymmetric due to factors which could not be calculated. Many slabs were sectioned and the penetration measured and cam corrected accordingly. Current for the arc circuit was obtained from a Lincoln S.A.E. 800 ampere welder for thin alloy surfaces and from a special motor-generator for currents up to 3,000 amperes for thick alloy surfaces.

The furnace mounted on the planer bed is provided for preheating the slab and working on it with the arc while it is hot. Adjustable speed is provided on the planer bed.

The operation for this experimental making of composite metals may be briefly described, as follows:

The slab (.04% to .06% carbon, .20% to .30% manganese) is put in the furnace and suitable ground connection made to it. The alloy is applied in shallow pans. These pans are very thin low carbon steel and are melted in the process. The bottom of the pan is covered with the correct amount of alloy. In the case of making 18-8, ferrochrome of the low carbon specification broken down to 10 mesh is used, together with nickel shot. Molybdenum, columbium, manganese may be added, depending on the grade of alloy wanted. The pan is then completely filled with slag, the height of the pan being designed so that when level full the right amount is present. This slag is composed of waste slag from an electric furnace in which 18-8 has been made together with sand and calcium fluoride. The slab is now heated in the furnace with the alloy and slag in the proper location. An excess of slag is applied around the margin of the pans to keep the metal from flowing off the slab when the operation is in progress.

The slab is heated to a temperature of about 800 Deg. C. as determined by pyrometer with the top of the furnace covered. The carbon arc welding operation is started after the cover has been partially removed and proceeds from one end of the alloyed surface to the other. A 6″ oscillation of the arc and 20″ travel was found suitable for obtaining the specimens required for testing the composite material throughout the complete rolling and processing and final testing. On 2″ thick slabs 1800 amperes, 45 to 50 volts across the arc, 1.6″ per minute planer bed travel were found suitable. Under these conditions, the metal alloyed would stay molten from ¾ to the total length of the travel, depending on the alloy being made. This was found to be a very important matter. After sectioning many alloyed slabs, it was shown conclusively that no failure of obtaining a perfect bond, over 100% of the area of contact, was ever encountered without striking evidence being visible on the surface.

Thus the process was developed to the point at which there could never be any uncertainty relative to this most important consideration. Any unusual condition resulting in the presence of blow holes or slag inclusions is immediately evident on the surface of the alloyed metal. This advantageous set of conditions would be predicted by anyone who

has had experience with carbon arc welding under the conditions under which this alloying is done.

After the alloying operation, the slab is removed from the furnace and cooled. The slag is easily removed when the slab is cool. The subsequent operations in the making of the finished product occur about as follows:

The surface of the alloy is given a light grind to remove scale and uneven spots. It may also be grit blasted. The slab is then put in the heating furnace preparatory to rolling. In the case of the test slabs, the hot rolling was first done to reduce and spread the alloy. The long dimension went into the rolls parallel to the axis of the rolls. Rolling was done in two stages—first, down to about ½" thickness and allowed to cool. Later the material was hot rolled on down to ⅜", $\frac{3}{16}$", 14 Ga. The material was then annealed and pickeled, and in some cases cold reduced down as low as 20 Gage.

No serious difficulty was encountered in rolling operations. Some special handling is required on account of the unavoidable tendency to curl due to difference in contraction coefficient of the two metals forming the composite.

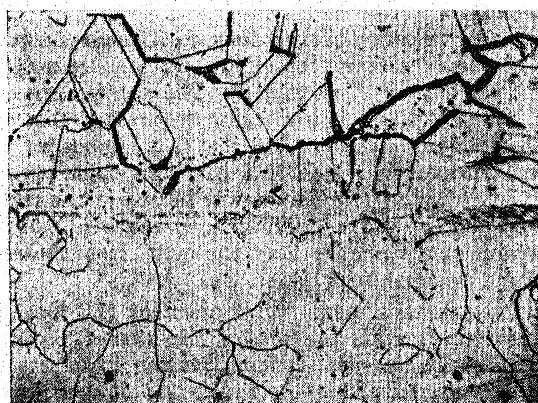


Fig. 9. Micro-structures of completely processed 18-8 clad steel, 14 gauge sheets. Showing in greater detail the bond structure. 500 X.

Results of Chemical Analysis.—There is given herewith typical chemical analysis of the alloy component of the composites made by carbon arc welding by the methods described. It is fairly obvious that the process is controllable to produce alloys in the form of composites within predetermined specifications. While the experimental apparatus was crude and difficult to control, every cause of variation was explored and the difficulties corrected in the design of the commercial equipment hereinafter described.

Physical Nature of the Bond.—There are reproduced herewith photomicrographs, Figs. 2–9, inclusive showing the nature of the bond between low carbon steel and stainless, as well as the condition of the metals forming the composite. The illustration Fig. 10 showing the

carbon steel etched away from the stainless (flat specimen in center) shows the most desirable physical contour of the bond. It will be noted that the bond does not occur in a smooth plane. An apt analogy is the case of two optical flats wrung together. They cannot be separated by tension normal to the bonded surfaces, but may be slipped apart. The non-planer bond in this composite metal is entirely free from this defect of bonding. The illustration showing the presumably martensitic structure in a very thin layer at the bond is characteristic of the process. That this layer in the bond does not affect the physical behavior is shown by the bent and severely deformed material. Many tests have been carried out in an attempt to break the composite metals apart in the bond. None has been successful.

The most severe test in the stainless carbon steel composite is the blister test where local heat is applied to the stainless side with an oxy-acetylene blow pipe. The slightest defect in bond will result in a blister where the metal is heated. No such defects have been found.

Typical Analysis Data on Surface Alloyed Slabs
Analysis of Surface

Table 1

18-8 20% Cladding 2″ Slab

C	Cr	Ni	Preheat	Speed in per min.	Current Amp.	Arc Voltage
.08	17.52	8.52	800°C	1.55	1800	44
.08	18.60	8.23	800°C	1.61	1800	45
.06	18.36	8.92	800°C	1.52	1800	49
.07	17.6	8.07	800°C	1.53	1800	45

Table 2

18-8 Molybdenum

C	Cr	Ni	Mo	Mn	Preheat	Speed in per min.	Current Amp.	Arc Voltage
.06	18.21	9.34	2.70	1.28	800°C	1.55	1800	49
.06	18.20	9.34	2.40	1.16	800°C	1.51	1800	49
.07	19.86	10.68	3.10	1.38	800°C	1.52	1800	45
.08	19.22	9.41	2.60	1.90	800°C	1.50	1800	45

Table 3

12 Cr

C	Cr	Preheat	Speed in per Min.	Current Amps.	Arc Voltage
.09	11.97	800°C	1.6	1800	43
.08	12.59	800°C	1.6	1800	42
		17 Cr			
.09	18.33	800°C	1.71	1800	44
.06	17.28	800°C	1.7	1800	45
		26 Cr			
.12	25.08	800°C	1.68	1800	45
.09	29.6	800°C	1.71	1800	44

The reason for this perfect score is perfectly simple. Had something gone wrong in the alloying operation, it would have been immediately discovered and the defect repaired by metal arc welding, using a stainless rod before the metal was rolled. There are no defects in the rolled metal for the reason that it would not have been rolled had there been any defects present. Further, in the case of 18-8, the martensitic structure in the bond is stronger than either the normal stainless or the carbon steel. It would not be expected that the stronger metal would break before the weaker.

Cost of Composite Metals Made by Carbon Arc Welding.—The factors which comprise the total cost of making composite metal by this method are ones with which steel mills are accustomed to deal so that cost of the product may be easily calculated. Thus, the alloy cost for the 18% chromium, 8% nickel metal is roughly 8¢ per pound. One 2,500 ampere carbon arc will make about 2½ pounds of the alloy

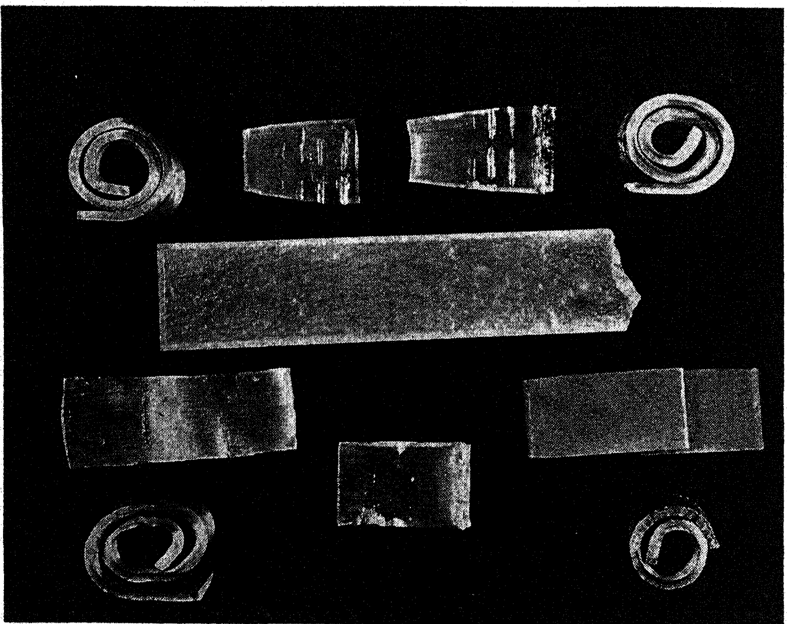


Fig. 10. Samples of composite metal made of low carbon steel and 18-8 deformed, to show that bond does not fail under any conditions. Center flat piece shows non-planer character of bond.

on the surface of a preheated slab per minute. The power taken from the line is about 1.2 k.w.h. per pound of alloy made. Carbon electrodes, slag etc. are almost a negligible factor in the cost. Cost of preheating slabs may vary from $2.00 to $5.00 per ton.

The out-of-pocket cost of material, heat, power and labor, to obtain a 20% cladding of 18-8 on low carbon steel and hot rolling is of the

order of $104.00 per ton of composite. The cost of making the alloy on the surface of the slab is approximately 15¢ per pound for 18% chromium and 8% nickel. Of the total of 15¢ per pound for this alloy, approximately 8¢ is for ferrochrome and nickel shot; the remainder being the cost of operating the process. The 18-8 metal being the most expensive ordinarily used represents the highest costs.

For costs of processing the composite beyond hot rolling a great deal depends on what is required. Pickling, shot blasting, cold reduction, polishing or other operations may be carried out at usual costs for these operations.

Adaptability of the Process.—A particular feature of the process is that it may be used by a steel producing plant which is not equipped with an electric furnace and trained personnel to produce solid stainless steel.

Since both the thickness of the slab worked on and the thickness of the alloy applied may be varied, the process is adaptable to the production of composite metals having a very thin coating of alloy. Perfection of the modern cold reduction process has opened up possibilities of a composite made of low carbon steel with a very thin coating of perhaps 17% chromium on one or both sides. Tin plate with as much as 40 pounds of tin per ton is a high grade product but it seems quite likely that the same steel with 40 pounds per ton of 17% chromium on the surface would offer longer life and better corrosion resistance. The same conditions apply to a comparison with galvanized steel. With an out-of-pocket cost of applying 17% chromium of the order of 10¢ per pound and an extra cost for shot blasting or belt grinding before pickling where the cladding is applied to only one side, the cost of the composite is still comparable to the cost of tin plate.

Chapter XX—Arc Welded Table Roller for Steel Mill Service

By JAMES GOODELL,
Designer, Kearneysville, W. Va.

There is no equipment in the steel plant that is subjected to as severe usage as the table roller. Many designs have been made but it has remained for arc welding to provide the means of making a strong, durable, light and cheaply constructed roller.

Table rollers are made by all steel plants and by companies making steel plant equipment. They are also used in industries other than steel mills for conveying materials.

The rollers are turned by electric motors, usually by means of shafting and bevel gears. The steel to be rolled is taken, or comes from a furnace, and is placed on top of these rotating rollers and thus conveyed to the mill, where it is rolled, and then carried by other rollers to the shears, then to the cooling beds and to the finishing department.

Table rollers are designed to meet the conditions imposed on them. Those near the mill must be large and strong to take the impact of large slabs of metal and must be placed close together due to the short lengths of hot metal. Other rollers, further from the mill are made lighter and spaced farther apart, having only to convey the rolled and elongated products. The design submitted as Fig. 1 can be modified to meet all of these conditions, although in this study of saving to the industry, the lighter finishing table rollers are not included.

By referring to Fig. 1, it will be seen that the author's table roller is made by welding to a central plate MK-C, a shaft at each end. These shafts have slots drilled and sawed in one end so that plate MK-C will fit into slot, where it is to be welded. The shafts also have ribs MK-D welded on opposite sides, as shown. Other ribs, as shown at D-1 on assembly set up, may be welded direct to plate marked C for large rollers or where rollers are subjected to extra severe conditions of impact. Work is set up on V blocks and a special clamp marked F is made to hold and center the work while tack welding. After welding shafts, ribs and thrust collar in place, the half rollers marked E are welded to side edges of plate marked C. To obtain a high quality wearing surface on shaft journals 40 to 50 carbon weld metal is welded to shafts. Roller is now complete except finishing and balancing by adding weld metal if necessary.

Fig. 2 shows dies used for hot pressing the half rollers marked E. The top die is bolted to press plunger and bottom die to the press base. Various sizes of half bushings and half circle male pieces are used to make any diameter of roller desired.

In order to show the prevalent types of rollers now in use and the savings that accrue from the arc welded design, the author shows in Fig. 3, for comparison purposes, a sketch of six different types of rollers together with weights, costs, savings and percent of savings. All rollers shown have the same general dimensions as the arc welded design.

The detailed cost data is given in table below. This shows how the results tabulated on Fig. 3 were obtained. These costs are based on the present market price of rolled steel, and on advertised prices of steel castings. The pound price of the larger castings is less, partly due to the cost of pattern being spread over a great weight. The time required to do certain work was obtained from those having experience, and the rate per hour includes overhead and is common to all estimates for the same class of work. The welding cost is based on laying down 8½ lbs. per hour with one quarter inch electrodes. This is believed to be a conservative figure. The cost of electric current, electrodes and overhead expense, is included in hour rate with wages, the latter being 75c per hour.

DETAILED COST DATA FOR TABLE ROLLER DESIGNS, FIGS. 1 AND 2

ROLLER MK-A—ARC WELDED DESIGN

Weights		
791 lbs. steel plates	@ 2½¢ per lb.	$ 19.77
127 lbs. steel shafting	@ 3¢ per lb.	3.81
Flame Cutting		
24 ft. of plates 1¼" thick	@ 8¢ per ft	1.92
Getting material and laying out plates—1½ hrs.	@ $1.30 per hr.	1.95
Forming cylindrical plates—2 pcs. per roller	@ 24¢ each	.48
Machining ends of plates MK-C—1½ hrs.	@ $1.30 per hr.	1.95
Machining U-grooves in plates MK-D—1½ hrs.	@ $1.30 per hr.	1.95
Layout, drill and saw slots in Shafts A & B—2 hrs.	@ $1.30 per hr.	2.60
Drilling and countersinking plates G—½ hr.	@ $1.30 per hr.	.65
Welding		
Setting up and fitting for tack welding—2 hrs.	@ $1.30 per hr	2.60
Tack welding—½ hr.	@ $1.30 per hr.	.65
56 lbs. arc welding lising ¼" Dia. Electrodes	@ 16¼¢ per lb.	9.10
Machining		
Turning roller and shafts—5 hrs.	@ $1.30 per hr.	6.50
Key seating—1½ hrs.	@ $1.30 per hr.	1.95
	TOTAL COST........	$ 55.88

ROLLER MK-B

With forged shaft, rolled tubing cylinder and arc welded disc at each end.

413 lbs. shafting	@ 3¢ per lb.	$ 12.39
4 ft. of 12" Dia. tubing	@ $15.00 per ft	60.00
Forging shaft—6 hrs.	@ $1.80 per hr.	10.80
Turning shaft preliminary to assembling and welding—4 hrs.	@ $1.30 per hr	5.20
Arc welding 10 lbs. of $\frac{3}{16}$" electrodes	@ 30¢	3.00
Machining—5 hrs.	@ $1.30 per hr	6.50
Key seating—1½ hrs.	@ $1.30 per hr.	1.95
	TOTAL COST........	$ 99.84

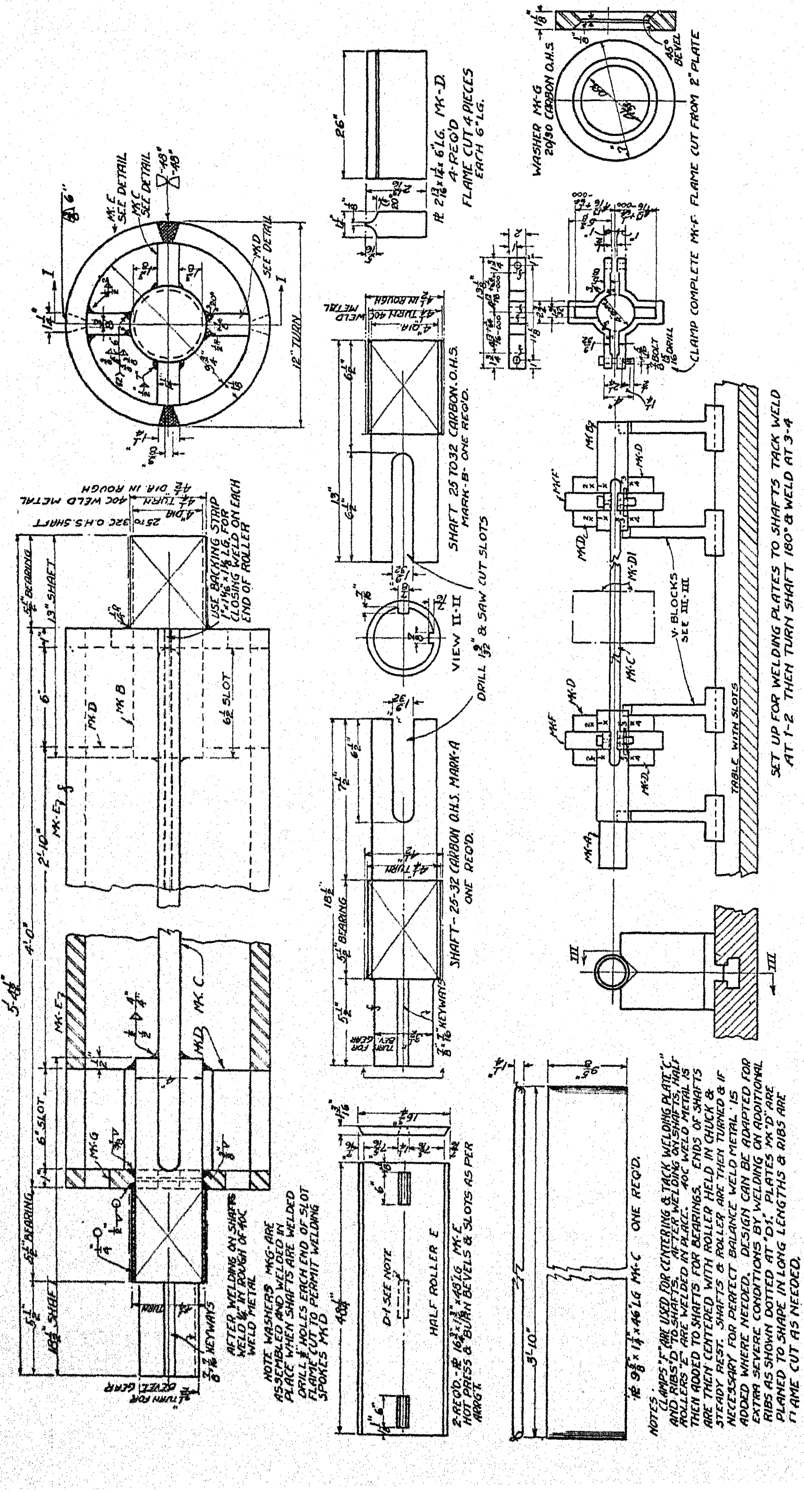


Fig. 1. Design of arc welded steel table roller.

ROLLER MK-C

Steel cast cylinder with steel cast ends shrunk in place.

1168 lbs. steel casting	@ 12¢ per lb.	$140.16
Boring cylinder ends—6 hrs.	@ $1.30 per hr.	7.80
Turning end pieces for shrink fit—6 hrs.	@ $1.30 per hr.	7.80
Assembling ends—4 hrs.	@ $1.30 per hr.	4.20
Machining roller after assembling—8 hrs.	@ $1.30 per hr	10.40
Key seating—1½ hrs.	@ $1.30 per hr.	1.95
	TOTAL COST	$172.25

ROLLER MK-D

With steel cast cylinder and a continuous rolled shaft.

291 lbs. rolled steel shafting	@ 3¢ per lb.	$ 8.73
796 lbs. steel casting	@ 12¢ per lb.	95.52
Turning shaft—3 hrs.	@ $1.30 per hr.	3.90
Boring roller—3½ hrs.	@ $1.30 per hr.	4.55
Key seating, fitting keys and forcing shaft in place —16 hrs.	@ $1.30 per hr.	20.80
	TOTAL COST	$133.50

ROLLER MK-E

Solid roller made of a rolled steel shaft with ends forged.

1800 lbs. rolled steel	@ 3¢ per lb.	$ 54.00
Forging ends—15 hrs.	@ $1.80 per hr.	27.00
Turning—8 hrs.	@ $1.30 per hr.	10.40
Key seating—1½ hrs.	@ $1.30 per hr.	1.95
	TOTAL COST	$ 93.35

ROLLER MK-F

With roller cast solid on rolled shaft with flat spots forged on shaft.

1500 lbs. steel casting	@ 10¢ per lb.	$150.00
291 lbs. shafting	@ 3¢ per lb.	8.73
Forging flat spots on shaft—2 hrs.	@ $1.80 per hr.	3.60
Turning roller and shaft—8 hrs.	@ $1.30 per lb.	10.40
Key seating—1½ hrs.	@ $1.30 per hr.	1.95
	TOTAL COST	$174.68

Data under MK-A in table give the detailed cost of making the arc welded design of table roller. Fig. 1 gives the piece marks that are used on this cost sheet. The costs given are based on making rollers on a production basis. The half roller plates MK-E, (Fig. 1), are pushed through a continuous furnace and heated to 1600 degrees F. for pressing. The cost of dies is included in the overhead. Please note the low cost of machining this type of roller as compared to the cast and forged rollers MK-C, E and F on Fig. 3. This is due to the accuracy of pressing and fitting the smooth plates and shafts so that only a light truing cut is needed, while two cuts are needed for the other "jobs."

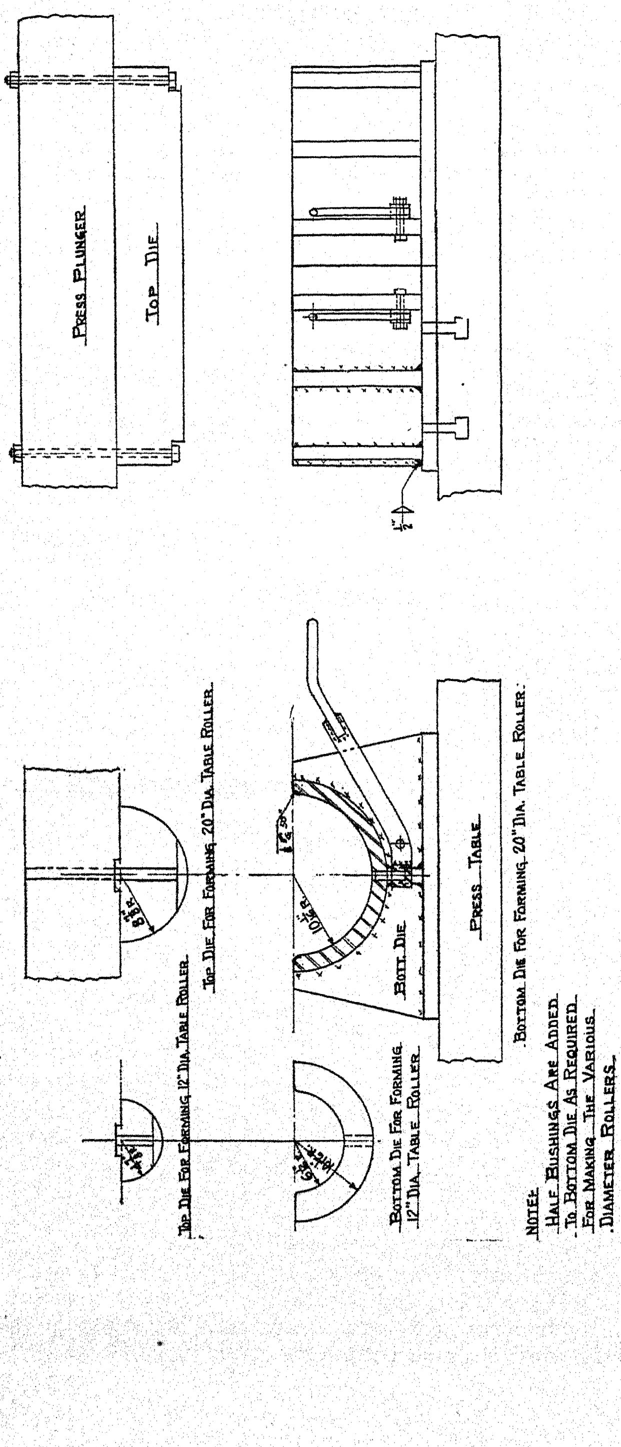


Fig. 2. Dies used for hot pressing half rollers.

This low machining cost also applies to the present method of making tube roller MK-B on Fig. 3. It will be seen, however, that the total cost of this roller is high, due mainly to the high cost of tubing, this item alone costing more than the completed arc welded roller, which is made of common plates and rounds available at any steel plant. The arc welded roller also has the advantage of strength, over the tube welded type, due to its solid rib in one direction and ribs added as required in the other direction.

The tube type roller, in order to get high wearing quality on journals is made from a 40 to 60 carbon shaft with disc attached to shaft by welding as shown by roller B, Fig. 3. Much breakage occurs to this type of roller due to welding to a high carbon shaft without preheating. This would not happen to the arc welded design with its low carbon shaft.

The design shown on Fig. 1 being stronger and less in weight can readily replace the heavy steel casting and steel forging type of roller by using proportionately heavier material on all parts that make up the roller. The additional weight in parts could be assembled with practically no extra work and at only a slight increase in cost due to the additional weight. Due to the high temperature maintained in the solid type roller, while rolling hot steel, it is the author's opinion that this is detrimental to the life of the roller and to the supporting bearings. The arc welded roller being hollow will dissipate the heat more rapidly, will reduce the load on bearings, will keep in better alignment and can be made at a saving of 40 to 68% over the solid type. See Fig. 3 for cost comparison.

For purposes of figuring the proportionate cost saving to the industry, it is believed that to use the costs for roller A shown in table and Fig. 3 for the design shown in Fig. 1, would be a fair average.

Fig. 3 gives the proportionate cost saving due to arc welding as per Fig. 1 over each of the designs of rollers in common use, listed as B-C-D-E and F on Fig. 3. Their average cost is \$134.72. The average cost of the hollow rollers B-C and D is \$135.20 and the average cost of the solid rollers is \$134.01. To use the average cost of \$134.72 as the cost of previous designs then gives a saving for the new arc welded design of \$78.84, or a saving of 58.6% over the previous designs in common use.

The gross savings accruing to the steel industry through the general adoption of the arc welded design (Fig. 1), rather than make replacements with the designs now in use, is determined by multiplying the saving per roller by the average number of rollers per mill, and this result by the number of mills using rollers. By actual count a 36" universal plate mill has 300 rollers—another plate mill has 250. One merchant mill has 418 rollers—another 400. A very conservative average of the heavier rollers is two hundred per average mill. The number of mills owned by the United States Steel Corp. is given in their annual report of December 31, 1937 and the Bethlehem Steel Corp. lists the mills in their annual report of same date. The number of mills in these corporations of the type that use rollers totals 255. The total steel production of these two corporations as given in these same reports for 1936 is 22,900,000 gross tons. The total steel production of the United States in 1936 was 47,768,000 gross tons. Assuming the same proportion exists between steel production and mills using rollers in the U. S. as exists in the above named corporations the number of mills in the

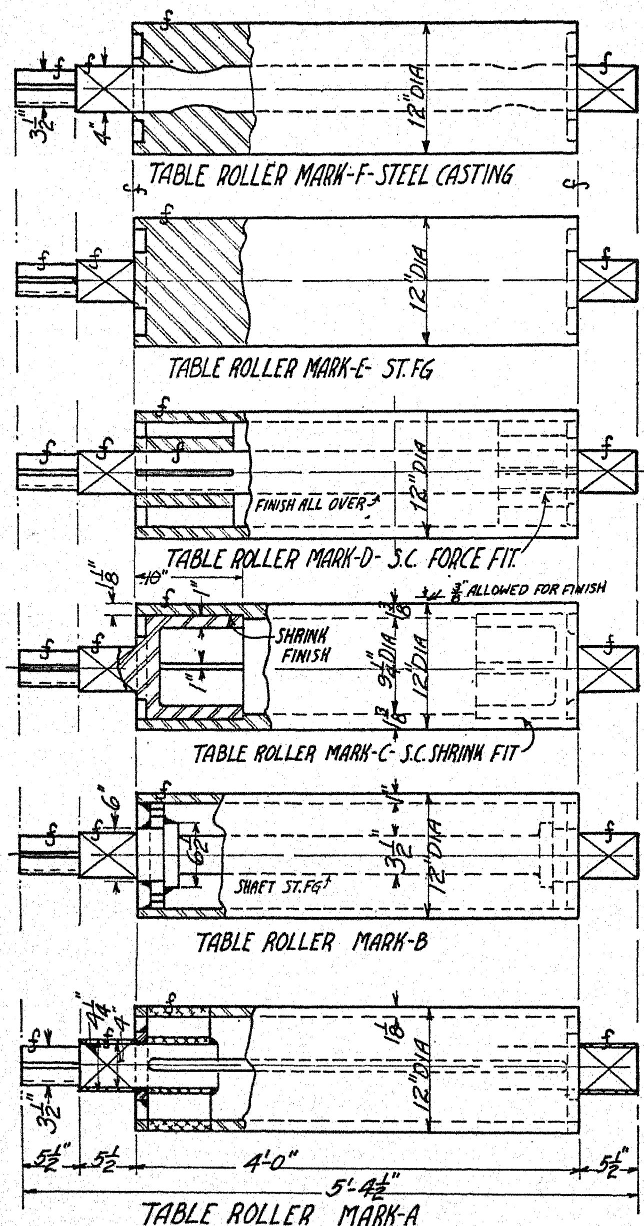


TABLE SHOWING COMPARISON OF TABLE ROLLER WEIGHTS, COSTS & PERCENTAGE OF SAVINGS ALL COMPARED WITH THE ARC WELDED TABLE ROLLER MARK-A-

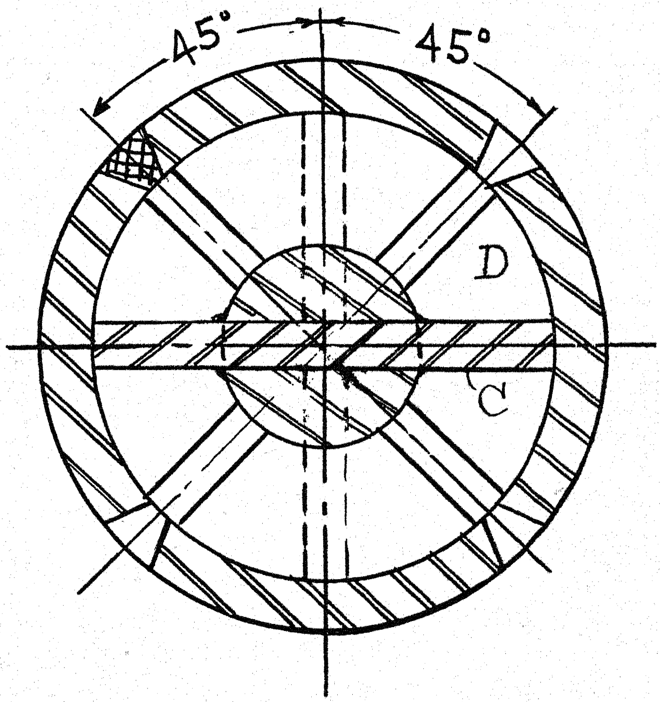
PIECE MARK	WEIGHT	COST	SAVING	PER CENT OF SAVING
A	918	$55.88		
B	883	99.84	43.96	44
C	1168	172.29	116.41	$66\frac{1}{2}$
D	1087	133.50	77.62	58
E	1800	93.35	37.47	40
F	1791	174.68	118.80	68

COMPARISON OF THE ARC WELDED TABLE ROLLER DESIGN WITH VARIOUS TYPES OF ROLLERS AS USED IN THE STEEL MAKING INDUSTRY

Fig. 3. Weight and cost comparisons of six types of rollers.

United States using rollers is 530. According to the "World Almanac" figures, all other countries combined produced 1.46 times as much steel as the U. S. alone did in 1936. Assuming the proportion of steel production to mills using rollers, exists in foreign countries, as in this, would give 774 mills in foreign countries using rollers. Therefore, the total number of mills in the steel industry using rollers is approximately 1304. The total number of rollers at 200 per mill would be 260,800.

With a saving of $78.84 per roller, the gross saving to industry would eventually be $20,561,000 by the general adoption of arc welded roller shown on Fig. 1 as compared to the average cost of the rollers now in use, based on the costs in this country. Since foreign countries are constantly placing orders for steel plant equipment in this country, foreign prices are probably not much different. With a depreciation and replacement of ten per cent this would make an annual average saving of $2,056,100 for the steel industry due to using arc welded rollers.



It might be asked why the average cost for comparison with the arc welded rollers was used rather than the next lowest priced one, namely MK-E on Fig. 3. It will be seen that this is the heaviest roller and it is very doubtful if a motor and gearing designed for possibly half this load would give satisfactory service under steel plant conditions. Then why was the arc welded roller not compared with tube roller MK-B on Fig. 3? There might be some conditions for light work where the latter could be

used, and the saving shown is exaggerated, but in many places tube rollers would not be strong enough and for average conditions it is believed the method used gives the fairest comparison.

One of the advantages in using the arc welded design, Fig. 1 is that lighter rollers could be used at the mill tables, and for reversing or three high mills, due to quicker "pick up" or acceleration of the lighter loaded motors, the capacity of these mills would be increased. A very important advantage is that while with the present designs, when a shaft breaks, the whole roller is reduced to the value of scrap steel, with this new arc welded type, when a shaft breaks, the portion of short shaft remaining can be flame cut from the center rib plate MK-C on Fig. 1. Then a special slotted shaft, having four ribs (MK-D on Fig. 1) welded at angles of 45 degrees to the position of the ribs on the original shaft, can be welded to center plate MK-C.

This will be made clearer by a sketch (See Page 1211). New slots are flame cut in roller for welding the additional ribs, MK-D, that have been welded to the new special shaft. This new shaft is welded along its slot where it fits into plate MK-C as far as can be reached and the shaft and parts completed as shown on Fig. 1. By this means, this design for arc welding would allow a reduction in spare rollers. Special slotted shafts with four ribs welded on would be carried as spares and used for various diameters and lengths of rollers. The use of the arc welded design would encourage the standardization of bearings and parts, and reduce the upkeep charges, since it is cheaper to use a short shaft length larger in diameter than needed to keep them all alike, rather than to keep spares for many odd sizes.

The lower costs proven for the arc welded roller, the greater service life due to using low carbon steel for welding and high carbon steel for shaft bearings, the efficiency due to quicker reversing of rotation and to keeping better alignment of the lighter, cooler rollers, the low maintenance cost described—all these contribute to lower prices of steel. The many modern conveniences containing steel are thus made available to more people.

Chapter XXI—Redesign of a Rotary Plow for Arc Welding

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A rotary plow of the type herein discussed is new and is a great help to the farmer inasmuch as it plows, discs and harrows all in one operation, leaving the soil with a perfect seed bed. It is also used for cultivating or pulverizing by merely operating at higher speed.

Tall corn stalks or stubble, wheat stubble, weeds, thistles or vines are no barrier to this machine. During the plowing operation, all such stubble, weeds, etc. are cut into small pieces and thoroughly mixed with the soil. These plows will be made in various sizes.

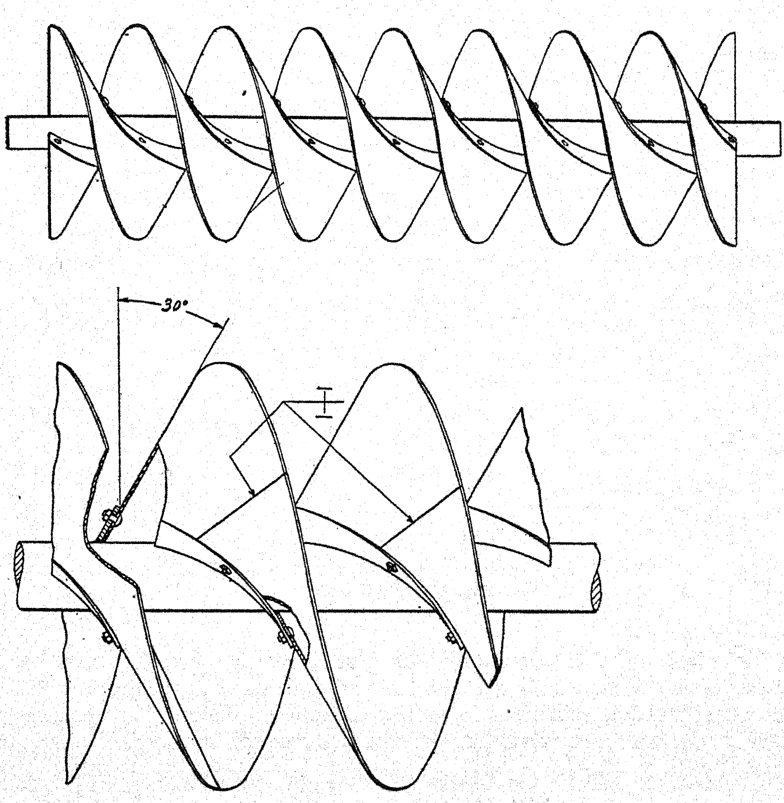


Fig. 1. Rotary cutter of arc welded plow.

In this paper a six-foot rotary plow is discussed. A six-foot plow will plow a strip six feet wide in one operation.

The rotary cutter of a six-foot plow is connected to the power take-off shaft of a 30 H.P. tractor. The action of the rotary cutter propels the plow over the ground, the tractor merely furnishing the power to operate the cutter and guide the plow by its being attached to the drawbar.

One of these plows has been thoroughly tested and in almost continuous operation since its completion ten months ago and has proven entirely satisfactory. The only real problem was the cost of manufacture. Therefore it was decided to redesign this machine so as to reduce the cost of manufacture but still maintain the quality and rigidity. The very interesting and beneficial result was obtained by using only 3 castings weighing 19 pounds instead of 25 castings weighing 340 pounds, and substituting arc welded steel construction, resulting in a design which is of simple construction, pleasing appearance, more durable and considerably lower in cost, as is shown farther along in this discussion.

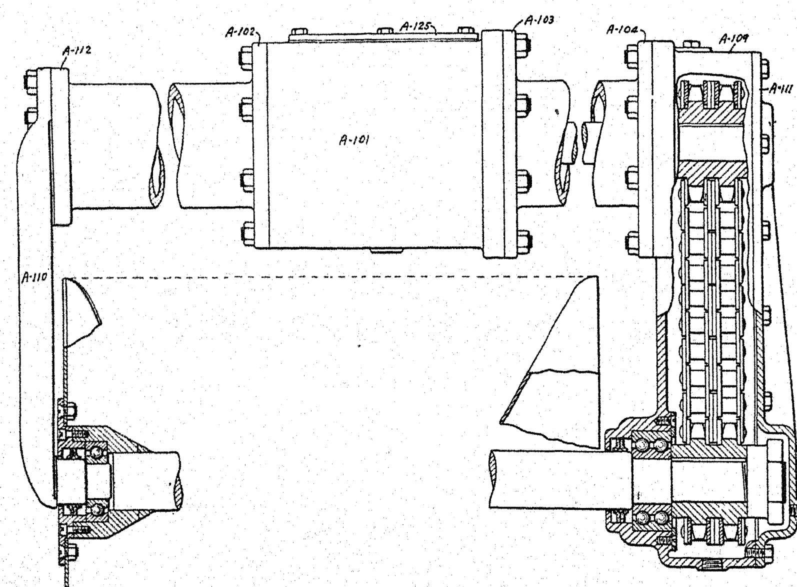


Fig. 2. Cutter shaft.

It might be well to mention here that a saving in weight was not attempted since the weight is required to hold the plow in the ground. On the other hand it will be shown that without sacrificing the necessary weight required in the machine, the cost was reduced considerably.

Description.—A rotary cutter (See Fig. 1), 14″ diameter and 6 ft. long, consists of a $2\frac{1}{2}$″ dia. shaft around which are welded two spirally formed bars to which the cutter blades are bolted. The cutter

blades are made from 7 ga. plow steel discs formed to shape and butt welded as shown, each disc making about one and one-third turns of the spiral. The double spiral requires ten sections. After the sections are butt welded, the cutter is sand-blasted to remove all scale and to polish the surface.

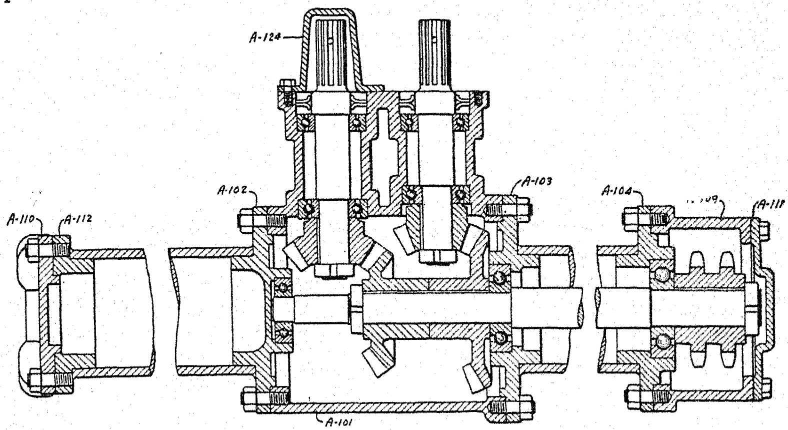


Fig. 3. Gear case of arc welded rotary plow.

The first impression may be that this cutter is the same as the well known spiral or screw conveyor, but there is a considerable difference. The conveyor has one angle which is the angle of the spiral while the cutter has two angles, the angle of the spiral and the angle of the face of the blade in relation to the axis of the spiral as shown at bottom in Fig. 1.

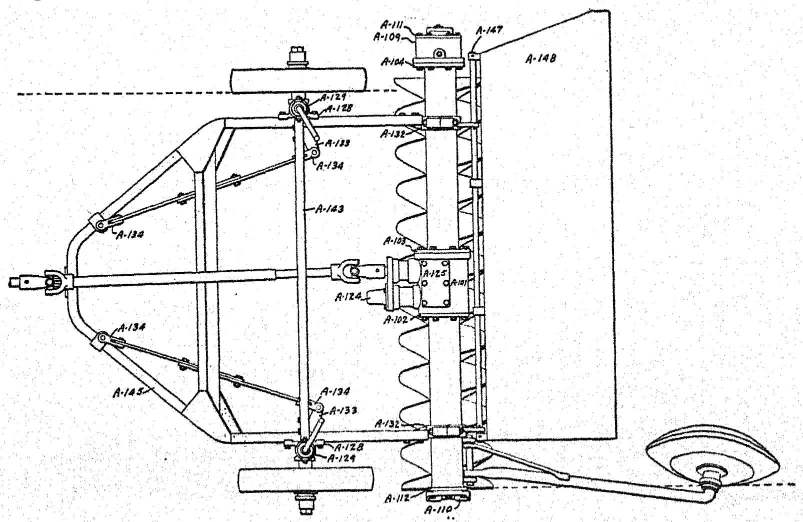


Fig. 4. Telescoped universal drive shaft.

The cutter shaft (See Fig. 2), is mounted in ball bearings at one end to the end bearing arm and the other end in the chain case. The shaft is operated by the sprockets and chain enclosed within the chain case. The drive sprocket is keyed to the drive shaft which passes through a pipe spacer, from the chain case to the gear case (See Fig. 3), and is driven by one of two bevel gears which mesh with bevel pinions. The reason for two drive shafts and gears is to provide for two different speeds without the use of a gear shift. It is not necessary to change the speed very often, only when it is desired to plow a different depth.

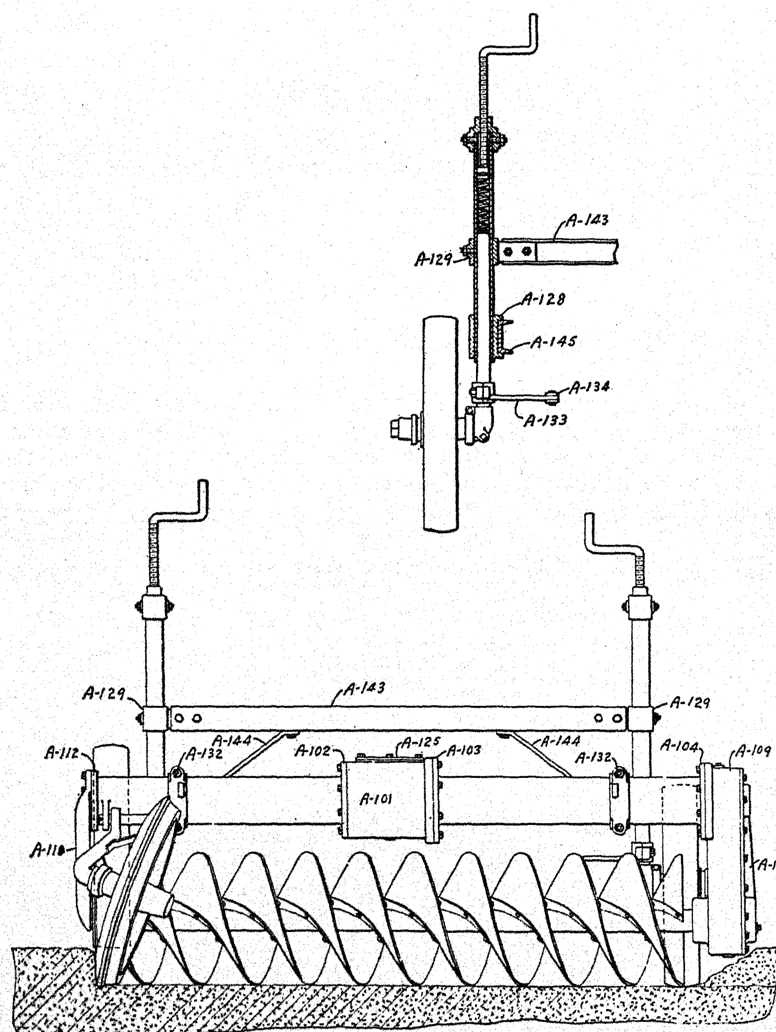


Fig. 5. Details of plow. Above—device for regulating height of frame in relation to wheels.

One of the two drive shafts is connected to the power take-off of the tractor by the telescoped universal drive shaft (See Fig. 4).

The two speeds of the rotating cutter are approximately 150 R.P.M. and 250 R.P.M.

The cutter and drive unit is supported by one end of a channel iron frame. The other end of the frame is attached to the drawbar of the tractor. Wheels on each side of the frame, between the cutter and the tractor, serve to gage the depth of the cutter. Height of the frame in relation to the wheels is regulated by adjusting screws and cushion springs against the end of the wheel shaft (See top of Fig. 5). These wheels are of steel welded construction and purchased from the dealer. To the rear of the machine is a heavy cast iron furrow wheel (See Figs. 4, 5 and 6), which runs in the furrow and holds the plow in line, this wheel is also purchased from the dealer.

Operation.—The plow being attached to the drawbar of the tractor and power supplied to the cutter from the tractor take-off shaft, the cutter is rotated and the tractor is advanced. The cutter rotating down in the direction of travel (See Fig. 6), cuts the dirt out as it advances and carries this dirt underneath and out behind the cutter. A shield prevents the dirt from being thrown back too far and also serves to level the top of the deposited dirt. The furrow wheel holds the plow in line against any side draft caused by the spiral cutting action of the cutter in the dirt.

Comparison.—In comparing the old cast design with the new welded design only the parts changed by the new design have been considered.

The line drawings, Figs. 1, 2, 3, 4, 5 and 6, showing the parts assembled, are of the old design, although the cutter as shown in these figures is of welded construction. The parts which are numbered in the line drawings are those which have been changed directly or indirectly by the change in design. In Table I the part number for the welded

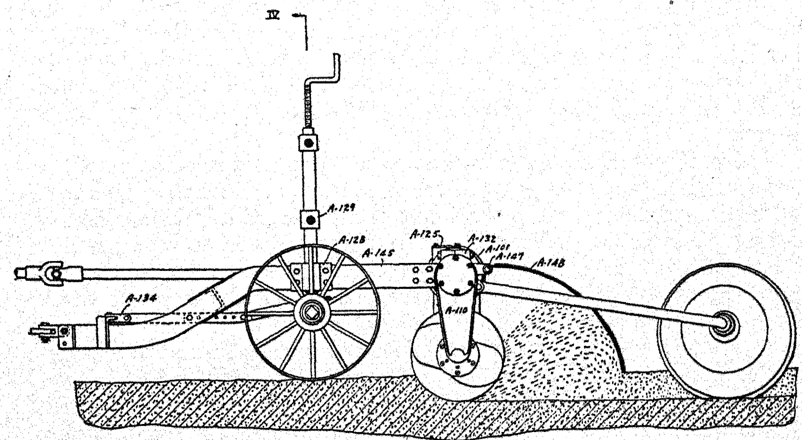


Fig. 6. Operation of rotary plow. Cuts dirt out as it advances and carries it back underneath the cutter.

construction is followed by the letter W, as for example, the cast gear case is No. A-101 and the welded gear case is No. A-101-W.

The accompanying drawings and tables give all the necessary data for comparison of the two designs.

The data for the cast construction was obtained from the cost and time sheets when the machine was constructed and the data for the welded construction was obtained from "Procedure Handbook of Arc Welding Design and Practice," fifth edition and from actual experience.

The detailed costs shown in all the tables except Table IV are based on construction of one machine only, without any jigs or templates and the savings can be considered as being very conservative. In each case, the cast construction cost was figured at a minimum. Even the pattern costs are not included in the costs shown, except in Tables III and IV and if only one machine was made the pattern costs would be charged to that machine, in which case, as shown in Table III, the saving in the welded construction over the cast construction increases from 29.9% to 49.3% on the parts redesigned and from 14% to 26% on the complete machine.

Table II shows the financial savings for each part as being from $.40 to $13.75 which is from 1% to 69.6% or even 100% for the several parts which were eliminated. The savings shown on this table would be a great deal more if the pattern cost had been considered.

The only part which was changed in general appearance is the frame A-145 and by this change expensive bends were overcome and seven parts were eliminated—two each of parts A-128, A-129, A-144 and part A-143. The cost of the frame was reduced from $41.27 to $27.52 at a saving of $13.75 or 33.3% without even taking into consideration the saving due to the seven parts being eliminated.

It is estimated that 150 machines will be manufactured the first year and Table IV shows the estimated costs of one machine when manufactured in this quantity with the use of machining jigs, welding jigs, and templates.

To give a fair comparison, the pattern cost should be considered, when constructing 1 or 150 machines and the cost distributed proportionately, which has been done in Tables III and IV. On this basis, the final savings per machine in lots of one is $226.14 or 26% and in lots of 150 $109.70 or 17% which is $16,455.00 on the 150 machines in one year.

These figures may appear misleading as the first impression would be that there is a greater saving per machine in lots of one than in lots of 150 but that is due to the pattern cost being charged to one machine, of the cast construction, in lots of one and proportioned to each machine in lots of 150. In fact, if the pattern cost was charged to the first machine and 149 more machines were manufactured the result would still be a saving, per machine, of $109.70 or 17%.

It is interesting to note in Table II every conclusion shows a saving for each part redesigned from cast construction to welded construction.

Other savings and advantages of the welded construction over the cast construction are the elimination of pattern storage space and pattern insurance, also the delay in obtaining castings and the loss from defective castings.

TABLE I—COST OF NONWELDED CONSTRUCTION

PART No.	NAME OF PART	PARTS REQ'D	MATERIAL				LABOR			TOTAL COST PER MACHINE
				WEIGHT LBS.	COST PER LB.	COST PER MACH.	LABOR PER HR.	LABOR HRS.	COST PER MACH.	
A-101	Gear Case	1	C. S.	70.0	$0.15	$10.50	$1.00	26.3	$26.30	$ 36.80
A-102	Flange—A-146 to A-101	1	C. S.	20.0	.21	4.20		4.6	4.60	8.80
A-103	Flange—A-119 to A-101	1	C. S.	24.0	.195	4.68		5.0	5.00	9.68
A-104	Flange—A-119 to A-109	1	C. S.	21.0	.21	4.41		4.6	4.60	9.01
A-109	Chain case	1	C. S.	59.0	.145	8.55		19.5	19.50	28.05
A-110	Cutter shaft end brg. arm	1	C. S.	21.0	.21	4.41		11.0	11.00	15.41
A-111	Chain case cover	1	Hi. Test C. I.	13.0	.165	2.15		4.9	4.90	7.05
A-112	Flange—A-146 to A-110	1	C. S.	12.0	.225	2.70		3.1	3.10	5.80
A-124	Drive shaft cover	1	C. I.	4.0	.25	1.00		.7	.70	1.70
A-125	Gear case inspection plate	1	C. I.	3.0	.25	.75		1.3	1.30	2.05
A-128	Wheel shaft guide bracket	2	C. S.	17.0	.25	4.25		5.6	5.60	9.85
A-129	Cross brace support	2	C. S.	9.0	.315	2.82		3.6	3.60	6.42
A-132	Strap—A-145 to A-119 & A-146	2	C. S.	30.0	.225	6.75		7.4	7.40	14.15
A-133	Wheel shaft arm	2	C. S.	11.0	.25	2.75		4.2	4.20	6.95
A-134	Wheel shaft arm link	4	C. S.	9.2	.315	2.89		1.6	1.60	4.49
A-143	Frame brace	1	3″ x 4.1 lbs. [x 4′8″	19.3	.05	.97		.6	.60	1.57
A-144	Corner brace for A-143	2	M.S. ½ x 1½ x 18″	7.8	.05	.38		1.4	1.40	1.78
A-145	Frame	1	4″ x 6¼ lbs. [x 15′	94.0	.05	4.70		34.0	34.00	41.27
	Frame spreader	1	4″ x 6¼ lbs. [x 4′3″	27.0	.05	1.35				
	Frame plates	4	St. Pl. 3/16″ x 5″ x 11″	12.0	.06	.72				
	Frame hitch L's	2	3″ x 2″ x ⅜″ L x 4¾″	5.0	.05	.25				
	Frame link bracket	2	M.S. ½″ x 2″ x 9″	5.0	.05	.25				
A-147	Shield shaft	1	½″ pipe x 5′8″	4.3	.10	.43		.5	.50	.93
A-148	Shield	1	16 Ga. St. 28½″ x 6′4″	38.4	.07	2.69		12.5	12.50	16.76
	Shield	1	M.S. ¼″ x 1¼″ x 24′8″	26.2	.06	1.57				
	TOTALS	38		562.2		$76.12		152.4	$152.40	$228.52

TABLE II—COST AND WEIGHT COMPARISONS, CAST AND WELDED

CAST CONSTRUCTION							WELDED CONSTRUCTION							SAVINGS		
PART NUMBER	PARTS REQ'D	WEIGHT LBS.	MATERIAL COST	LABOR HRS.	LABOR COST	TOTAL COST	PART NUMBER	PARTS REQ'D	WEIGHT INCL. ELECTRODE	MATERIAL COST INCL. GAS-POWER & ELECTRODE	LABOR HRS.	LABOR COST	TOTAL COST	FINANCIAL $	FINANCIAL %	WEIGHT LBS.
A-101	1	70.0	$10.50	26.3	$26.30	$36.80	A-101-W	1	69.6	$6.22	30.18	$30.18	$36.40	$ .40	1.0	.4
A-102	1	20.0	4.20	4.6	4.60	8.80	A-102-W	1	22.6	1.45	6.74	6.74	8.19	.61	7.0	† 2.6
A-103	1	24.0	4.68	5.0	5.00	9.68	A-103-W	1	17.0	1.27	6.28	6.28	7.55	2.13	22.0	7.0
A-104	1	21.0	4.41	4.6	4.60	9.01	A-104-W	1	17.6	1.25	5.89	5.89	7.14	1.87	20.0	3.4
A-109	1	59.0	8.55	19.5	19.50	28.05	A-109-W	1	58.3	4.64	21.30	21.30	25.94	2.11	7.5	.7
A-110	1	21.0	4.41	11.0	11.00	15.41	A-110-W	1	25.2	1.81	6.32	6.32	8.13	7.28	47.0	† 4.2
A-111	1	13.0	2.15	4.9	4.90	7.05	A-111-W	1	12.5	.80	2.76	2.76	3.56	3.49	49.6	.5
A-112	1	12.0	2.70	3.1	3.10	5.80	A-112-W	1	11.0	.73	4.01	4.01	4.74	1.06	17.4	1.0
A-124	1	4.0	1.00	.7	.70	1.70	A-124-W	1	1.8	.20	.90	.90	1.10	.60	35.3	2.2
A-125	1	3.0	.75	1.3	1.30	2.05	A-125-W	1	3.4	.17	.70	.70	.87	1.18	57.5	† .4
A-128	2	17.0	4.25	5.6	5.60	9.85	....	......	....This	Part E	liminat	ed........	....	9.85	100.0	17.0
A-129	2	9.0	2.82	3.6	3.60	6.42	....	......	....This	Part E	liminat	ed........	....	6.42	100.0	9.0
							A-132-W									
A-132	2	30.0	6.75	7.4	7.40	14.15	A-132A-W	2	24.7	2.28	6.00	6.00	8.28	5.87	41.4	5.3
A-133	2	11.0	2.75	4.2	4.20	6.95	A-133-W	2	5.5	.40	1.70	1.70	2.10	4.85	69.6	5.5
A-134	4	9.2	2.89	1.6	1.60	4.49	A-134-W	4	8.2	.50	3.50	3.50	4.00	.49	10.9	1.0
A-143	1	19.3	.97	.6	.60	1.57	....	......	....This	Part E	liminat	ed........	....	1.57	100.0	19.3
A-144	2	7.8	.38	1.4	1.40	1.78	....	......	....This	Part E	liminat	ed........	....	1.78	100.0	7.8
A-145	1	143.0	7.27	34.0	34.00	41.27	A-145-W	1	183.4	10.97	16.55	16.55	27.52	13.75	33.3	†40.4
A-147	1	4.3	.43	.5	.50	.93	A-147	1	4.3	.43	.50	.50	.93			
A-148	1	64.6	4.26	12.5	12.50	16.76	A-148-W	1	66.4	4.33	4.66	4.66	8.99	7.77	46.3	1.8
Totals......	28*	562.2	$76.12	152.4	$152.40	$228.52	Totals.........	21	531.3	$37.45	117.99	$117.99	$154.44	$73.08	....	30.9

* See parts not numbered in Table I.

TABLE III—SUMMARY OF COST COMPARISONS, LOTS OF 1

	Cast Construction	Welded Construction	Savings	
REDESIGNED PARTS				
Material Cost	$ 76.12	$ 37.45	$ 38.67	50.8%
Labor Cost	152.40	117.99	34.41	22.5%
Material and Labor Cost	228.52	155.44	73.08	32.0%
Material Overhead 10%	7.61	3.74	3.87	50.8%
Labor Overhead 55%	83.82	64.89	18.93	22.5%
Total Cost Without Patterns	319.95	224.07	95.88	29.9%
Pattern Cost	122.05	....	122.05	100.0%
Total Cost With Patterns	$442.00	$224.07	$217.93	49.3%
Weight	562.2 lbs.	531.3 lbs.	30.9 lbs.	5.4%
REMAINING PARTS				
Parts Purchased, Bearings, Chain, Wheels, Bolts, Universal Shaft, etc.	$122.82	$122.82	....	....
Material Cost	76.26	76.26	....	....
Labor Cost	87.50	87.50	....	....
Material and Labor Cost	286.58	286.58	....	....
Material Overhead 10%	19.90	19.90	....	....
Labor Overhead 55%	48.12	48.12	....	....
Total Cost Without Patterns	354.60	354.60	....	....
Pattern Cost	7.00	7.00	....	....
Total Cost With Patterns	$361.60	$361.60	....	....
Weight	1112.8 lbs.	1112.8 lbs.	....	....
COMPLETE MACHINE, LOTS OF 1				
Material Cost	$275.20	$236.53	$ 38.67	14.0%
Labor Cost	239.90	205.49	34.41	14.3%
Material and Labor Cost	515.10	442.02	73.08	14.1%
Assembly Cost	41.40	36.50	5.30	12.6%
Material Overhead 10%	27.52	23.65	3.87	14.0%
Labor Overhead 55%	154.93	133.09	21.84	14.0%
Total Cost Without Patterns	739.35	635.26	104.09	14.0%
Pattern Cost	129.05	7.00	122.05	94.6%
Total Cost With Patterns	$868.40	$642.26	$226.14	26.0%
Weight	1675 lbs.	1644.1 lbs.	30.9 lbs.	1.8%

Conclusion.—The proportionate cost saving of the welded design over the cast design is $102.25 or 42% per machine on the parts redesigned and $109.70 or 17% per complete machine when manufactured in lots of 150 which is the estimated production for the first year.

The gross savings on the 150 machines constructed the first year will be $16,455.00.

The service life of the machine has been increased in the welded design by the elimination of bolts which held castings to the frame, thereby making a more rigid construction in which there is no danger of bolts becoming loose or operating parts becoming misaligned, resulting in more efficiency and lower cost of maintenance.

The manufacturing cost being considerably reduced, allows for a reduction in cost to the user, who in this case is chiefly the farmer. On account of the lower cost, more farmers will be in a position to own one of these plows which will save them considerable time and expense in farm operation by their being able to plow, disc and harrow all in one

TABLE IV—COST AND WEIGHT COMPARISONS, LOTS OF 150

	Cast Construction	Welded Construction	Savings	
REDESIGNED PARTS				
Material Cost	$ 68.51	$ 33.71	$ 34.80	50.8%
Labor Cost	129.54	88.50	41.04	31.6%
Material and Labor Cost	198.05	122.21	75.84	38.3%
Material Overhead 10%	6.85	3.37	3.48	50.8%
Labor Overhead 55%	71.24	48.67	22.57	31.6%
Total Cost Without Patterns	242.58	141.14	101.44	41.6%
Pattern Cost	.81		.81	100.0%
Total Cost With Patterns	$243.39	$141.14	$102.25	42.0%
Weight	562.2 lbs.	531.3 lbs.	30.9 lbs.	5.4%
REMAINING PARTS				
Parts Purchased, Bearings, Chain, Wheels, Bolts, Universal Shaft, etc.	$110.54	$110.54		
Material Cost	68.64	68.64		
Labor Cost	74.37	74.37		
Material and Labor Cost	253.55	253.55		
Material Overhead 10%	17.91	17.91		
Labor Overhead 55%	40.90	40.90		
Pattern Cost	.05	.05		
Total Cost Without Patterns	312.36	312.36		
Total Cost With Patterns	$312.41	$312.41		
Weight	1112.8 lbs.	1112.8 lbs.		
COMPLETE MACHINE, LOTS OF 150				
Material Cost	$247.69	$212.89	$ 34.80	14.0%
Labor Cost	203.91	162.87	41.04	20.1%
Material and Labor Cost	451.60	375.76	75.84	16.7%
Assembly Cost	35.53	31.02	4.51	12.6%
Material Overhead 10%	24.77	21.29	3.48	14.0%
Labor Overhead 55%	131.69	106.63	26.06	19.0%
Total Cost Without Patterns	643.59	534.70	108.89	17.0%
Pattern Cost	.86	.05	.81	98.0%
Total Cost With Patterns	$644.45	$534.75	$109.70	17.0%
Weight	1675 lbs.	1644.1 lbs.	30.9 lbs.	1.8%

operation instead of several operations and at the same time leaving the soil in better condition for larger crops, all of which leads to a greater return to the farmer for his efforts and on his investment.

An interesting fact is that the farmer would be deprived of all these advantages to him if it were not for arc welding. This may appear to be quite a broad statement but nevertheless it is a true fact as the following statement will reveal.

At first the spiral blades of the rotary cutter, which is the essential part of the plow, were cast in sections and proved to be entirely unsatisfactory, being difficult to cast and could not be cast thin enough, also the surface was not smooth enough to permit the soil to pass freely between the blades, all of which was very effectively overcome by the use of arc welding as previously stated.

A concluding fact is that arc welding has made possible the satisfactory construction of this plow and thereby created a new industry which will be a benefit to all concerned.

Chapter XXII—An Arc Welded Coal Stoker for Residence and Other Heating

By Scott Van Etten,
Manager and superintendent, Colvan Stoker Co., Columbus, Ohio.

I have chosen as the subject of this paper the design of a standard type, worm feed coal stoker for residence and other heating. In this, gas flame cutting and electric arc welding enter largely into the fabrication and manufacture.

I have chosen this for the reasons: A—I have previously participated in the design and manufacture of such domestic coal stokers. B—I have been connected with a company or concern making such stokers as draftsman and shop superintendent. C—The design I describe has not been manufactured, sold or offered for sale previous to January 1, 1937. This size and type of stoker is used almost exclusively for domestic heating.

I have four definite objectives in making this design: First—To enable a small and not too extensively equipped shop to produce an efficient, thoroughly dependable machine, upon a strictly competitive basis, from standard and easily obtainable materials. At the same time I avoid large contract obligations with other suppliers of component parts, which is usually necessary to secure low enough prices. Electric arc welding and gas flame cutting are invaluable tools to securing this end; without them it would be impracticable for a small concern to enter this highly competitive field.

Second—To produce as many parts of the machine as possible under one roof and thus maintain close supervision of the quality and the quantities of stock and product.

Third—To produce a stoker, feeding up to 75 pounds of fuel per hour that will cost the user about $125. plus installation charges and with a plain thermostatic control.

Fourth—The most important objective with this design is to produce a machine that will not require a specially prepared or processed fuel known as "stoker coal," ordinarily needed by most machines, but will handle dependably and well the cheaper grades of soft coal known as "nut, pea and slack," and anything that will go through a 2″ or 2½″ screen at the mine. These grades contain just as many heat units as the more expensive grades. Most domestic stokers handle the first mentioned grades rather poorly and so we find a grade of small uniformly sized coal on the market, often oil treated for dust, that is priced as high as the better grades of lump, run of mine, etc. Therefore, these stokers do not effect any price economy in most cases. I overcome this defect with my design.

In order to accomplish this I use a much larger feed screw or worm, to allow larger lumps to pass, than is usually employed on a stoker of similar capacity,—4″ instead of the usual 2½″ to 3″—and run it at

slower speed to secure the same rates of feed per hour. Further, I have incorporated in this design two features that are specifically different from others: First, an inclined bar screen set 1″ wide, through which much of the slack and pea coal will fall directly into the feed worm, allowing the smaller percentage of lumps too large to feed, to go through. Second, a simple crusher or grinder, that really only fractures the lumps to a feedable size, and thence into the feed screw.

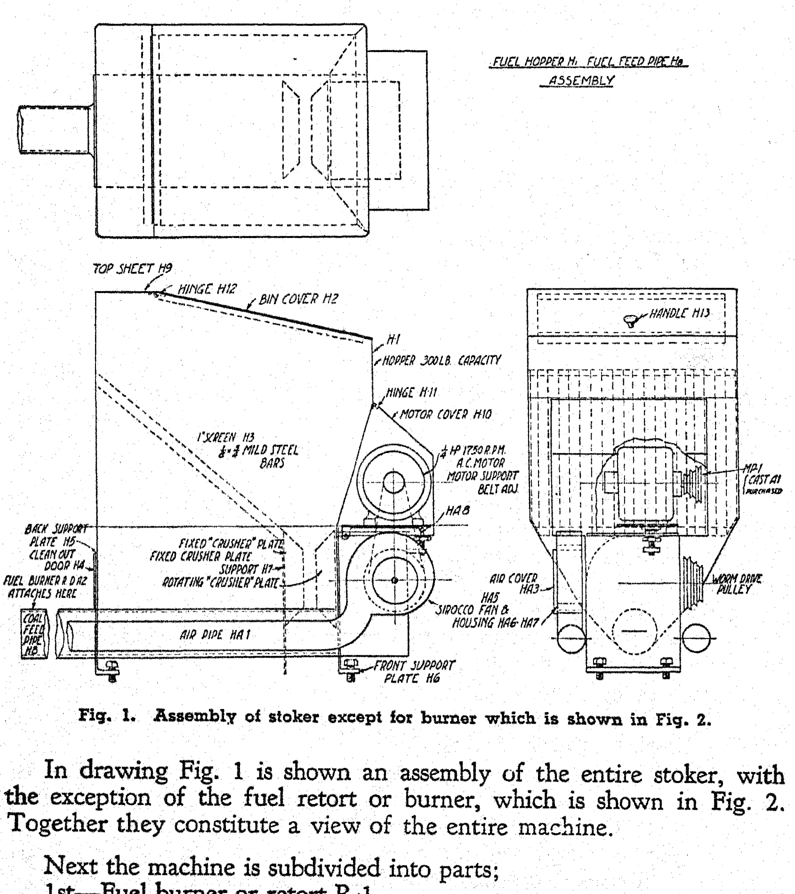


Fig. 1. Assembly of stoker except for burner which is shown in Fig. 2.

In drawing Fig. 1 is shown an assembly of the entire stoker, with the exception of the fuel retort or burner, which is shown in Fig. 2. Together they constitute a view of the entire machine.

Next the machine is subdivided into parts;
1st—Fuel burner or retort R-1
2nd—Coal feed pipe and hopper H-8 and H-1
3rd—Coal feed worm or screw W-S 1
4th—Fan, fan housing and air pipe H-F
5th—Transmission or "Gear box" T-C
6th—The coal breaker or crusher G-C
7th—Motor and motor mount and belt drive M-M

Taking up first the retort R. in drawing Fig. 2, it will be seen that I get away from a cast iron burner, which is used by most of the manufacturers and make it entirely of steel.

There are 7 parts:

The fuel cone R1
The top ring R2
The outer casing R3
The fuel feed pipe R4 and sleeve R5
The two air pipes R6
The air chamber bottom or closure R7

The fuel cone R1 is made from 8 gauge steel, flame cut to template outline. This can best be done by a flame cutting machine but the hand torch can do the work. By placing sheets of ordinary paper between the steel sheets, from four to six pieces can be flame cut at one pass, without much, if any, edge fusion and what little occurs can easily be broken apart. Next this piece is heated in a gas furnace to a low red, clamped on the line X-Y to a suitable cast iron anvil or form and with a few strokes of a smith's hammer shaped to the conical contour. It is then arc welded at the seam and to the fuel pipe R4 using $\frac{5}{32}''$ electrodes and about 125 amperes.

The top ring R2 is formed by rolling a piece of $1\frac{1}{2}'' \times \frac{3}{8}''$ machine steel, edgewise, into a ring $11\frac{3}{8}''$ O.D. arc welding it to the fuel cone R1 and the joint welded shut, using $\frac{5}{32}$ rod and 125 amperes of current.

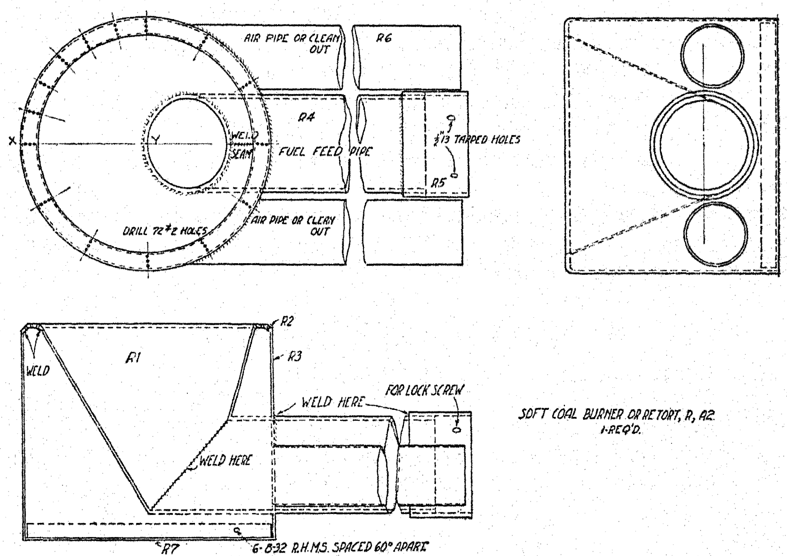


Fig. 2. Burner of arc welded stoker.

The outer case is made by flame cutting or shearing a $36'' \times 120''$ sheet of 10 gauge steel into 10 pieces and rolling each into a cylinder $11\frac{3}{8}''$ in diameter. The seam is then "tack" welded and the three holes for the fuel feed pipe R4 and two air pipes R6 are template marked and flame cut. This outer case is slipped over feed pipe R4 and arc

welded to the ring R2 and to the fuel pipe R4. The seam is welded shut and the two air pipes R6 are next welded in. 3/32", 1/8" and 5/32" electrodes are used and from 50 to 125 amperes of current as the thickness of the metal requires.

The fuel feed pipe R4, mentioned above, is made of 4" standard pipe. A piece 42½" long is flame cut into two pieces 21¼" long on a curved diagonal that will fit the opening in the fuel cone R1. A short piece of 4½" standard pipe R5 is cut 3" long, slipped over the straight end of R4 and welded all round and then R4 is welded in as above stated.

The two air pipes R6, (which are used interchangeably as either air inlet or dust clean out pipes, according to whether the stoker is made with the fan on the right or left side), are made by cutting a piece of 2⅝" seamless steel tubing 40" long into two pieces 20" long, on a long curved diagonal to fit the contour of casing R3 and manually are welded to it, using 3/32" shielded rod and about 35 to 40 amperes of current.

All welding on this retort must be carefully done with no air leaks, or the fire will follow down the air line and may cause burning and scaling of the retort. It is necessary to test the completed job thoroughly for such leaks.

The bottom of the air chamber is made of 22 gauge galvanized steel, blanked on a circle cutting machine and with a ¾" flange thrown up all along and cemented in with furnace cement.

The final operation on the retort is to drill at least 72, No. 2, (or larger, if so specified), holes through the top ring R2.

It is to be noted that these air holes are so drilled that the fire is always kept above the retort and not allowed to burn down into the fuel cone A1 or lower than the top of the casing. By doing this, the fire is prevented from damaging the retort, as so often happens with other makes.

ESTIMATED COST OF RETORT

Outer case	14½ lbs.	} @ 3½¢	
Fuel cone	12 lbs.		$1.10
Fuel ring	5 lbs.		
Fuel feed pipe	19½ lbs.	1.8′	.62
Air pipes	4½ lbs.	3.4′	.68
			2.40
Pan	2½ lbs.	@ 4¢	.10
Welding rod	4 lbs.	@ 38¢	1.52
		A total	4.02
Labor, by actual experience, 3 hours each, on 50 lots, at $.75			2.25
Shop overhead and power estimated (Total weight 42 lbs.)			.73
			$7.00

Against this, the best price I have on cast iron retorts is \$11.50 each, on a contract basis for 100, to which must be added freight and cartage, and a pro rata of pattern, core box, and core making costs. In addition to saving \$4.50 each, there is the added advantage of the strength of steel and the smoother surface of the fuel cone, allowing easier feed of the coal. The cast iron retort weighs 90 to 92 pounds each, thus, there is a saving in weight of 48 to 50 pounds.

By the use of arc welding, I make a proportionate saving on this item of 65% of the cost of the steel retort or about 38% of the cast iron retort, according to whether we figure saving on cost or purchase price.

The next part considered is the coal feed pipe H8 and hopper or fuel bin H1. The feed pipe, in which the feed worm rotates, is made from a 44″ length of 4″ standard pipe. A transverse slot is burned, milled or sawed 21″ from one end and a longitudinal slot is cut in the same manner along the top side of the pipe to meet the cross slot. This end of the pipe is heated in a gas furnace to a low red heat and using a suitable bell crank smith's lever, is opened up to make a shallow trough, which is next formed, while hot, over a suitable cast iron form or anvil. This part is shown in Fig. 1.

Next, the back support plate H-5 through which a 4½″ round hole and a 4″ x 5″ square hole (for clean out door) has been machined or burned is slipped over the pipe H8 and manually arc welded to it and the two wings of the trough, using ⅛″ rod and about 125 amperes of current. It is to be noted that the square hole is reinforced by pressing the flaps of the hole back and welding them to the sheet, using 3/32″ rod and 30-40 amperes.

The front support plate H6 is next welded on the front end of the pipe H8, using ⅛″ rod and 125 amperes of current. The hopper or fuel bin proper is made of 16 gauge steel. A 36″ by 96″ sheet is template-marked and either flame cut or sheared to correct size and shape for H1. It is then clamped to a specially made brake and all necessary bends are made, including the 1 top and front flanges. (This could be done in a regular sheet metal brake by making a few jigs or holding forms). Next this box is set over the pipe H8 and manually arc welded to it and the front and back support plates H6 and H5 to make the complete fuel bin. For this last welding use 3/32″ and ⅛″ rod and from 60 to 90 amperes of current.

The bin cover is made of 16 gauge black steel, cut and bent. The miters and upright corners are manually arc welded to make a stiff and strong cover H2. It is provided with a continuous, or "piano," hinge and suitable clamping handle. 3/32 electrodes and about 40 to 50 amperes are used.

The coal screen H3 is made of ⅛″ by 1″ steel strip set edgewise and manually welded to angle iron strips and tied together by a ¾″ x ¾″ angle iron brace. This work requires ⅛″ electrode rod and about 75 to 90 amperes of current.

ESTIMATED COST OF HOPPER AND FEED PIPE

1 sheet No. 16 black steel	60 lbs. @ \$3.32	\$2.00
1 pc 4″ pipe 44″	41 lbs. @ 3½¢	1.43
1 4½ nipple 3″		.12
1 pc No. 16 Ga. steel 2′ x 2′	8 lbs.	.28
50′ 1″ x ⅛″ black strip	16 lbs. @ 3.32	.60
3 angle iron strips	3¼ lbs.	.15
Handle, hinge and rubber smoke gasket		.60
Motor cover H10	2 lbs.	.15
Top plate H9 and clean out H4	3 lbs.	.10
Welding rod	3½ lbs.	1.33
		\$6.76
Labor, based upon actual making of very similar bin and pipe assembly in 50 piece lots, 5 hours each @ 75¢		3.75
Shop overhead, gas and power, estimated		1.40
		\$11.91

Against this, I have a bid from a local sheet metal shop, in lots of 50, made by the older methods of bolting, seam jointing, riveting, etc., of \$16.00 each and I have to supply and put on the pipe H8 already fabricated which I estimate to be at least \$2.50 or a total of \$18.50. This shows a proportionate saving of at least 75% on the cost of the welded bin as above outlined, or about 33⅓% on the price of the purchased bin.

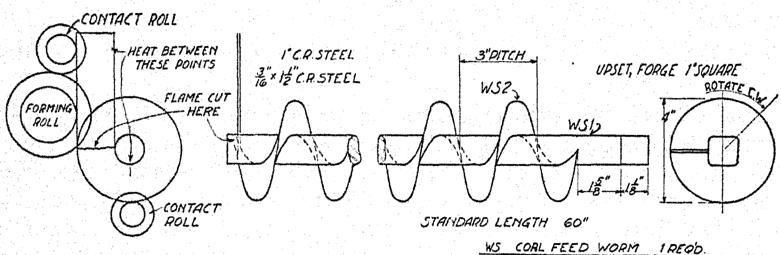


Fig. 3. Fuel feed worm of stoker.

The next unit is the fuel feed worm, or screw WS shown in Fig. 3. These worms are usually either cast iron or drop forged steel. The cast iron worm has been used extensively in the past but has fallen into disrepute on account of breakage and easily worn drive ends. It is expensive to cast, as it is best made in dry sand moulds and requires dry sand boxes as well as very good and costly patterns. In addition, considerable work is needed to clean them up and they are difficult to straighten if they come out of the sand with a bend or twist. The drop forged worm is much better but requires expensive dies and presses to make and only very high priced hammer men can forge them, especially if they are short pitch and deep threaded.

The best quotation I have on a 60″, 4″ dia. by 3″ pitch worm is \$12.50 on a contract basis. (A 3″ worm 3″ pitch worm is considerably less).

I have devised a rugged roller machine on which to make these worms, taking a suitable length of 1" round steel, (60" is the usual length), and winding a strip of 1½ x 3⁄16" steel around it on the correct spiral. This is quite difficult to do if cold, but a heated strip readily winds on and deforms to make the thread. After tack welding in several places to hold it in shape, the spiral is manually arc welded on both sides to the rod. The heating of the strip can be done in a gas furnace, but it is thin and loses heat rapidly, so preferably it is heated by a heavy electric current, from a special transformer with low voltage and large current capacity, which current is applied just ahead of the bending rolls.

The cost of the current will be more than offset by the time saving. The 1" rod above mentioned is first heated on one end, upset and forged to 1¼" square to make the driving end. There is about 20' of welding on this worm, done manually with ¼" shielded rod and about 175 to 200 amperes of current. If done while the strip is hot the current is materially reduced.

ESTIMATED COST OF WORM

1 piece of machine steel 61" long	13.6 lbs.	@ 3¼¢	$ .48
1 piece 3⁄16" x 1½" steel 13' long	13 lbs.	@ 3¼¢	.44
2½ to 3 lbs. welding rod		@ 38	1.14
			2.06
Labor on a 50 pc. lot at 2½ hrs. each at 75¢			1.88
Shop overhead, current, estimated			1.76
			5.70

A saving of at least 125% on the cost of the welded worm and of about 40% on the price of the drop forged worm.

The next unit is the fan and fan housing, (See Fig. 1). The fan is the usual Sirocco impeller type, of cast aluminum and is purchased, as no particular saving can be obtained by making these in small lots, by arc welding. This fan is only 6" in diameter and 2½" face. It will be noted that the speed of this fan is varied when the V driving belt, from the motor to the transmission, is changed to alter the feed. I have found this to be a great advantage over having a fixed air supply, as when the fan is placed directly on the motor shaft. When a low feed is used less air is required and while this does not follow a straight line law the combination of the adjustable air shutter and the variable fan speed enables the user to adjust the air to properly "clinker" the coal ash and yet not blow holes in the fuel bed, or blow it off the burner.

The fan housing is most economically produced in two stampings, a right and a left, including the 90° discharge elbow. One side has a 6" "cut out", covered by an adjustable air shutter or air shield, and the other stamping is left solid for attachment to the support. While the two halves could be "lipped" and "dove-tailed" together, a real saving can be effected by arc welding them together because of the lesser cost of the dies and the stamping, and on account of the elimination of noise due to vibration at the joint. The air discharge pipe is a standard lock seamed 2½" 29 or 30 gauge galvanized pipe.

The total cost of the fan and the housing is \$2.80. The welding on the housing is done with $\frac{3}{32}''$ shielded rod and about 25 amperes current.

The fifth item, the gear box or transmission, is one of the most important from the point of arc welding as it must be oil tight and amply strong. In this gear box, the ratchet type of intermittent drive is eliminated, nor is an extremely high ratio used in the worm gear reduction, as both types have developed difficulties with other makes, that are overcome in this design.

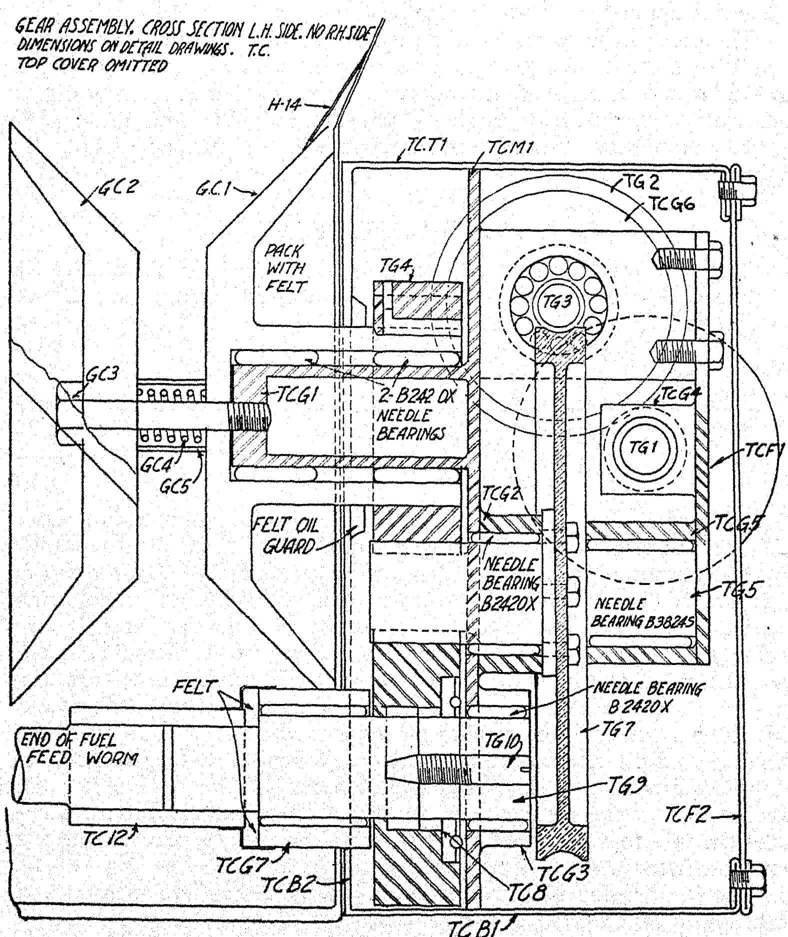


Fig. 4. Stoker gear box.

This transmission is shown in a side cross section assembly in Fig. 4. With the exception of the gears, bearings and necessary machine work, this gear box is made entirely by flame cutting and arc welding. Starting with the middle plate TCM1, a piece of seamless steel tubing $1\frac{9}{16}''$ OD,

¼″ wall x 3⅝″ long is clamped firmly in place and thoroughly welded on it. This tube is plugged at its open end with a ⅝″ plug welded in. The plate is then turned over and the bearing bosses TCG2 TCG3 and the two bearing lugs TCG6 are welded on, using ⅛″ and 5/32″ shielded rod and about 125 to 150 amperes of current.

The bearing boss TCG1 is next turned to 1.500 .001″.

The front plate TCF1 is prepared by clamping and arc welding to it the two bearing lugs TCG4 and the bearing boss TCG5. This plate TCG1 is bolted to the two lugs TCG6, after both have been jig drilled for 4, 5/16″ hex. cap screws. The whole assembly is then located by the turned boss TCG1 and the bosses TCG2, TCG3, TCG5, and the bearing, lugs TCG4 and TCG6 are *jig bored* and reamed to size. The plate TCB2 is bored for grinder plate hub, GC1 to pass through and the bearing boss TCG7 is inserted and welded in place. This plate TCB2 is then bolted into place and the boss TCG7 is bored and line reamed with the bearing hole in the boss TCG3.

The above assembly constitutes the complete bearing set up, and the rest of the transmission consists of the bottom plate TCB1, the two side plates TCR1 and TCL1 and the top plate TCT1, which has a cover plate TCT1-A through which certain of the gears, etc., are introduced in the assembly of the case. All the above plates are made of 16 gauge black steel and each is double bent on the front edges, one which is double thick on 4 edges to make a gasket seat for cover plate TCF2. After being formed as indicated, these four plates are clamped in position and arc welded all round to the back plate TCB2, tack welded to the middle plate TCM1 and where their edges contact. After the box is thus formed, its front flanges are disc ground true and flat to make a seat for the cover TCF2 and both are jig drilled and tapped for the cover screws. The cover plate TCF2 is formed with a double bent edge to give it stiffness and strength. All the welding on this 16 gauge steel is done with 3/32″ shielded rod and about 50 to 60 amperes of current.

The gears, shafts, needle and ball bearings, bronze bushings, etc., are made by the usual machine shop methods and manufacturing procedure which need not be gone into in detail, as arc welding and flame cutting and welding do not enter directly into their manufacture. They are to be made of the most suitable materials, steel, bearing bronze, etc., and to close limits and tolerances.

I estimate the weight and cost of this gear box, or transmission, as follows:

ESTIMATE OF WEIGHT AND COST OF GEAR BOX

1 piece machine steel ¼″x9″x11″	7 lbs.			
1 piece machine steel 3/16″x6″x8″	3 lbs.			
1 piece machine steel ⅛″x9″x11″	3½ lbs.	37½	@ 3¼¢	$ 1.22
5 pieces machine steel 16 gauge total	9			
7 pieces machine steel Assorted total	15			
Welding rod	3 lbs.		@ 38¢	1.14
Gears, shafts, etc., on contract, or our own make				8.40
Needle and ball bearings				1.80

All labor cutting, shearing forming and fabricating parts.
Building and machining the case and doing all welding, by actual test is less than 4 hours per case, in 50 case lots (200 man hours) 4 hrs. @ 75¢ 3.00
Shop overhead and power, estimated 1.90

Total weight about 54 lbs.......... $17.46

The best price I am quoted on a comparable and an acceptable transmission, with a cast iron case, on a contract basis of 200 minimum is $24.00 each plus freight. I could not equip to make them by other methods than by arc welding and flame cutting, for even that price unless I was assured a demand of at least 1000 transmissions. I can get a simple ratchet type of feed box for as low as $17.00, plus freight, but it has not proved satisfactory with some other makes. Neither of these boxes, the $24.00 or the $17.00 one, incorporate the coal crusher that I embody in this design.

The above analysis shows that by flame cutting and arc welding a saving of over 25% is effected on the purchase price of the bought transmission and of very close to one third, (33⅓%), on the actual cost of the steel case shown.

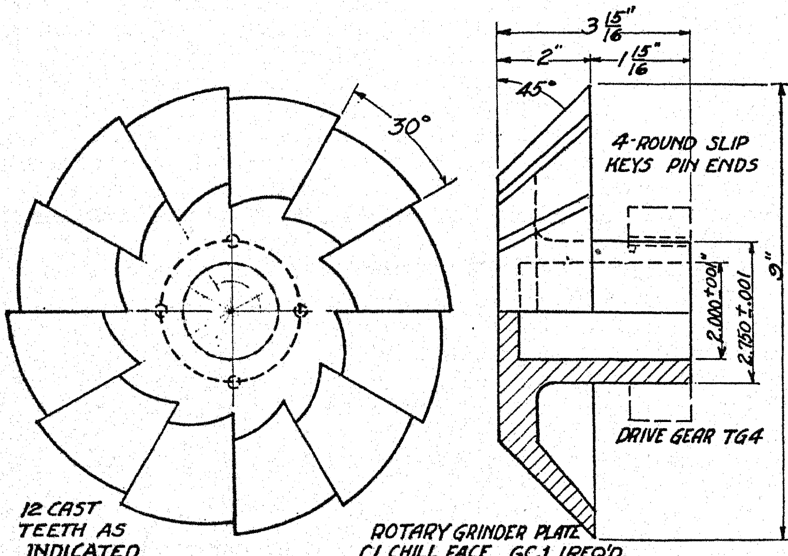


Fig. 5. Coal crusher.

The coal crusher, (See Fig. 5), is next to be considered. This is made of two ribbed, chilled face, cast iron plates. One of these plates is fixed and the other rotates at a slow speed. A steel retainer plate is welded to the side of the bin to take the pressure of the coal as it goes through. This is the only item, aside from the V belt pullies and the bronze worm wheel casting, that cannot be produced cheaper and/or better by arc

welding. These crusher plates could be fabricated by arc welding and hard faced in a similar manner, but the cost would be higher than the chilled castings, and while the life would probably be much longer, three years' service has not worn the experimental ones much, if any.

These castings cost 10¢ a pound and weigh 30 lbs.	$3.00
Machine work 1 hour	.75
	$3.75

In common with most other makes of domestic stokers this design calls for an AC, or DC, 1750 RPM motor. Many makes use a 1/6 HP but on account of the coal crusher I have found a 1/4 HP better. It is mounted upon a tipable steel shelf set on top of the gear case as indicated in Fig. 1 and provided with a simple screw adjustment at the front end to tighten the V belt. Suitable rubber pads and bolt bushings are provided to eliminate vibration and noise.

The cost of this mount and the 2, 3 step V belt pullies is $2.20.

This detailed statement of the making of this stoker is another case of taking longer to tell it than to do it. Most of the operations described, especially if spread over 50 to 100 lot jobs in proper order of manufacture, can be done in a surprisingly short time.

For instance the man hours involved in making the transmission case by flame cutting and arc welding are not as great as are required to make a similar casting in the foundry, taking the time for moulding, melting, pouring, breaking out and cleaning and snagging the castings.

As to the gross saving resulting to the stoker industry from the use of an all arc welded design of domestic coal stoker; there are about 1,000,000 such stokers sold annually in the United States and this is on the increase. An experienced manufacturer, having much larger and more expensive shop equipment and a larger working capital, could possibly produce a machine by other methods that would compete with a design such as I show. But, upon an even basis of shop facilities and capital, a saving of at least $20.00 per unit is effected, to say nothing of the saving made by the closely controlled stock and quick turnover possible through the methods I have given. A total economy, very conservatively stated, of at least $2,000,000 per year would follow general adoption of arc welding by the industry.

Now, as to the general economy and social advantages resulting to the community at large and mankind in general, by the use of automatic heat there can be no argument. The day is past when it is necessary to demonstrate an individual's ruggedness and endurance by going half frozen during our winters. No longer is it considered the sensible thing to do, as the writer did as a boy break the ice in the pitcher to perform our morning ablutions. The demand for dependable and automatic heat is here and to stay. The wider the benefits can be spread, the greater the advantages to health and personal comfort. The saving from reduced sickness is obvious. The specific economy of a stoker, adapted to burn the cheapest grades of coal, is also perfectly apparent. Much of the coal that my design is able to use is what has been in the past waste material to the mine owner and dead labor for the miner. Too many factors enter

to prevent a complete evaluation in dollars and cents saving, but I can cite my own experience to show some of the economy.

Four years ago it cost me $116.00 for the winter to heat my eight room house. I then began experimenting with stoker equipment and for the past three winters, I have used, per winter, not over 20 tons of Nut, pea and slack from the same mine, costing $2.50 per ton. Adding 75¢ per week for 20 weeks to cover the electric power, I made a saving of $50.00 per year. Translate this into the saving accruing to the average 10 to 12-ton user per winter and spread it over the entire country and the social and money savings effected will be enormous.

It will be noted that I have not put on a single element of ornament or more expensive design, just for the sake of appearance, but have made a strictly utilitarian machine, to cost the least possible. I have specified shielded arc welding throughout. I have found that the shielded arc metallic electrode produces a smoother and tighter job in the hands of the average worker.

As to increased service life and mechanical efficiency, I can not give specific test figures or results now, as steps are just being taken to manufacture this stoker; however, past experience and close adherence to standard engineering and machine shop practice, plus about 20 years welding experience, ensures a product comparable with the best on the market.

In closing, I want to emphasize the fact that, but for flame cutting and arc welding it would not be possible for the little fellow to get into this business as conditions are now, but with these tools a small group of us are going to try it.

Chapter XXIII—Redesign of Bread Slicer Formerly Made of Cast Iron

By ERNST DUESING,
Foreman, sheet metal and welding department, Oliver Machinery Co., Grand Rapids, Mich.

Our first successful attempt to replace a casting by arc welded steel dates back only a few years. When, in 1933, our production of woodworking machinery had decreased to only 11% of normal, we began manufacturing bread-slicing and wrapping-machinery. Upon discovery that some of the most expensive parts of the newly designed slicing machine were two reciprocating cast aluminum frames, (See Fig. 1), suspending the slicer knives, we decided to substitute an arc welded steel design, (See Figs. 2 and 3), for these aluminum parts.

Against much opposition in our organization, we installed in the fall of 1933 a 100 ampere arc welded. Little time was required to prove the superiority of the steel welded design over the previous cast aluminum to those opposed to arc welding for production purposes. The box section chosen for supporting members of the steel frame reduced the weight by 10%, allowed a 50% higher loading, and decreased the cost by 30%.

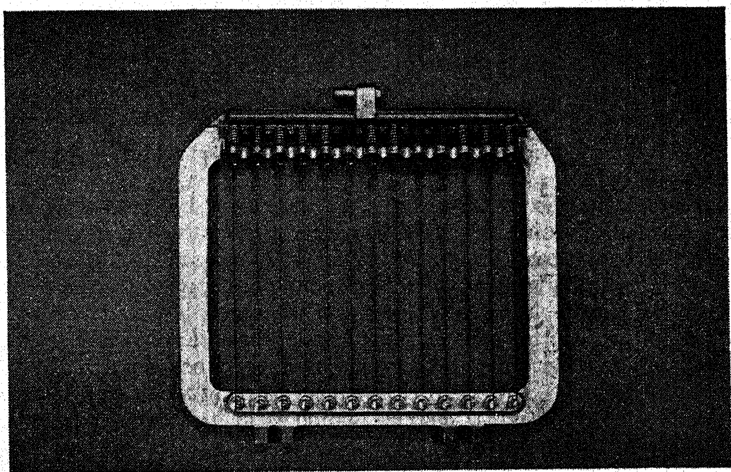


Fig. 1. Cast aluminum knife which was redesigned for arc welded steel construction, (See Fig. 2).

Encouraged by so favorable a comparison between the casting and the steel construction, we tried constantly to enlarge the field of application for our newly acquired arc welder. On this particular machine, however, the two above-mentioned knife frames, (See Fig. 2), remained

the only arc welded parts for more than two years. Aluminum and cast iron dominated the rest of the construction. Not until late in 1936, long after we had realized the necessity of redesigning this bread slicer, did an opportunity arrive to prove once more the advantages that cold rolled steel held over a casting.

The main housing used for this machine, (See Fig. 4), was of the conventional cast iron type. Besides not being entirely satisfactory from several other standpoints, one of the most frequently repeated complaints made by users of bread slicers, could be laid directly to the use of cast iron for this housing. High grade machinery used in the food industry requires a finish that is difficult, if not impossible, to obtain by the use of cast iron. A crinkle finish applied directly to

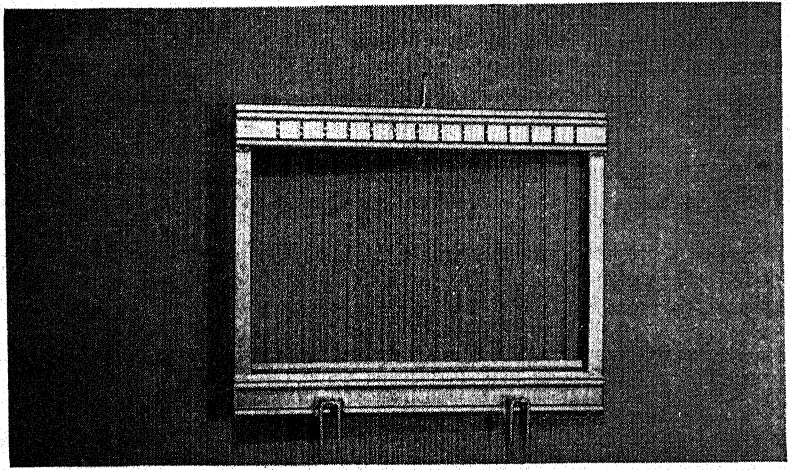


Fig. 2. Arc welded steel bread slicer knife.

the rough casting is highly durable. From a sanitary standpoint, however, it is entirely unsatisfactory. Because of the nature of its surface it cannot be kept clean. Expensive handfilling and sanding of the casting, prior to applying priming and enameling coats, will give the desired smooth and washable finish. Those few machines, however, which, in spite of careful crating, reach their destination without being chipped, are not long in service before paint and filler are knocked off in the most conspicuous places. Another disadvantage in using a cast iron filler lies in the fact that the white enamel, which is in great demand for our bread slicers, will gradually turn yellow.

The knowledge that cold rolled steel would provide us with a perfect base for a high grade and inexpensively applied paint job was, in itself, sufficient reason to give steel some consideration in the redesign of this bread slicer. Moreover, our insufficient knowledge in designing a completely arc welded steel housing was easily supplemented by building a few test machines. Where the previous cast iron housing had required two sets of expensive patterns and various not-less-costly changes in the finally adopted pattern, no special tools nor any other great outlay was

required to build a sample machine of cold rolled steel. The $\frac{3}{16}''$ thick steel plates primarily used for this housing were shaped on a metal cutting band saw and formed on a regular heavy hand brake. Changes, dictated by appearance and other factors, were easily made with hack saw, cutting torch, and the help of the arc.

While working on the new design and testing necessary changes, it became apparent that the arc welded construction would readily lend itself to many desirable improvements that on the old cast iron housing would have been difficult and expensive to obtain. These facts, most of which were not realized until we began studying the possibilities offered by an arc welded design, influenced the decision in favor of the machine which I am about to describe.

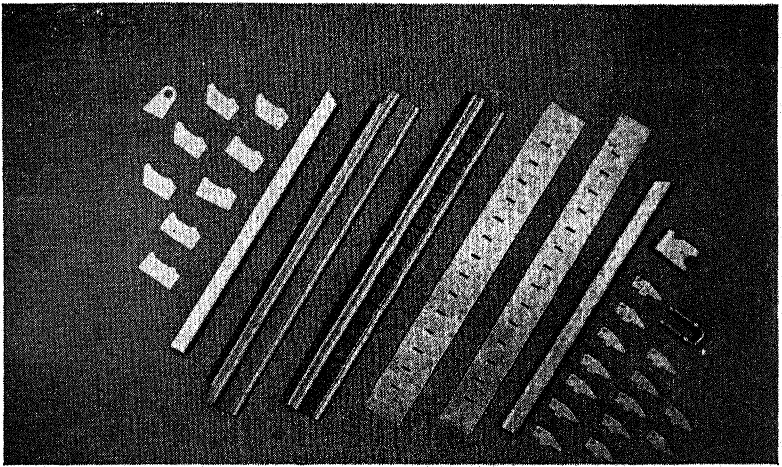


Fig. 3. Component parts of arc welded knife.

The principal parts of every bread slicer used for large scale operation are two reciprocating knife frames. Contrary to the straight up and down movement of the knives in the majority of the bread slicers on the market, the knife frames in our machine do not travel in a straight line. This design makes possible the use of durable ball bearings at all moving points instead of babbitt bearings and brass bushings. Since this arrangement proved to be very satisfactory and trouble free on the original cast iron machine, it was only logical to adopt it for the new arc welded slicer. Our fears that it might prove difficult in the arc welded frame to obtain accuracy and good alignment necessary for the use of ball bearings were soon dispelled. In fact, after completing the welding jigs for the assembly of the steel frame, the new method was found to be not only cheaper but produced also a much higher degree of accuracy than could be secured on the cast iron housing with the help of expensive boring mill operations.

The rocker, (See Fig. 5), is supported at the ends by the two ball bearings marked (a) and (b). In the case of the cast iron frame it was necessary to have the bearing on one end of the rocker floating, as

the distance between the two ball bearing housings varied as much as 1/8". Close observation showed that on the steel frame this distance never varied more than .015". And even this variation most likely was due not to the welding but to the unevenness in the plates used for the sides. Warping and gradual settling of the casting, often caused the ball bearing housings in the old slicer, which for greater accuracy were bored from one side, to be considerably out of line; while, on the steel frame, we experienced invariably an almost perfect alignment between both opposite bearings.

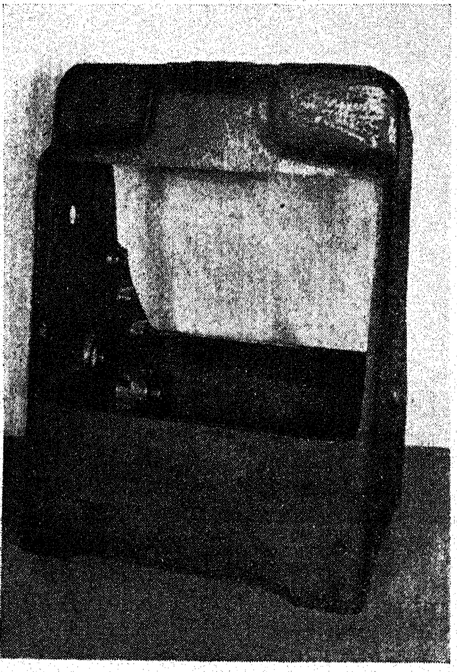


Fig. 4. Old-type cast iron housing.

Since the 3/16" side plates used for the arc welded slicer are not heavy enough to support a ball bearing, bushings are welded into the sides of the frame. These bushings, at low cost, are made from steel tubing on an automatic turret lathe. Except for a distance slightly less than the thickness of the plates, the outside of the tubing is left unfinished. This end is turned down to fit into a hole punched into the side of the frame. The hole in the bushing is reamed to approximately .0005" to .001" below ball bearing size. The correct size is obtained with a hand reamer at the final assembly of the machine.

This construction was found to be very satisfactory. The hole in the side plate locates the bushing easily and accurately. A clamp screw, which is used to press the bushing against the plate for welding also draws the plate firmly against the heavy welding jig; thereby, allowing

the welding heat to be carried away almost immediately and eliminating practically any distortion. The fillet welds fusing the bushing to the side plate can be made quite small, as this type of construction places very little strain on the welds.

The same procedure as outlined above is followed in providing a retaining box for the two ball bearings supporting the crank and pulley assembly. The rocker which supports the lower end of the up-and-down-moving knife frames, is kept in motion by the crank pin. A connecting rod joins the crank and the rocker. The pulley, forming part of the

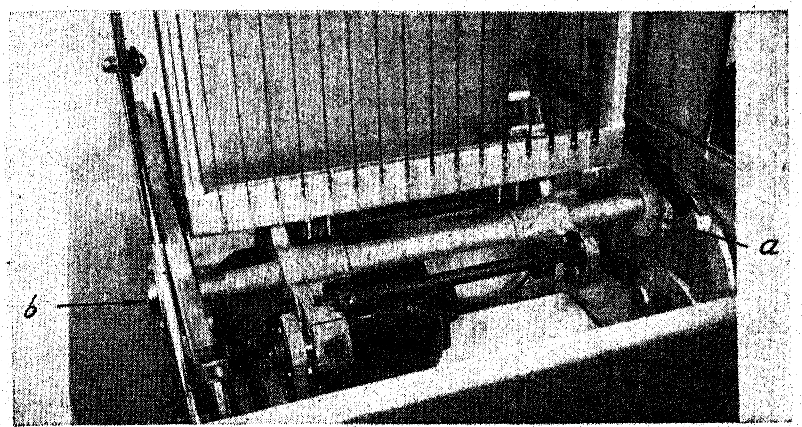


Fig. 5. Rocker supported at ends by two bearings, "a" and "b".

crank, is driven by a motor mounted on the side of the machine. Some trouble was originally encountered with this housing. The heavy, continually changing load created by the unbalanced crank required both a solidly welded housing and a retaining hole perfectly true in size and shape. Fearing that the welding would disturb the roundness of the housing, the inner diameter on the first few machines was left quite small, so that any unevenness caused by the welding could later on be corrected. That, however, required a rather expensive grinding operation after the welding was completed. Spurred by the desire to eliminate this additional cost, we soon learned that the proper procedure in welding and the correct size of the weld would not noticeably change the size of the hole nor affect its roundness. We do now use the same method that is applied at the smaller rocker shaft bearings. The housing is bored and reamed to within .0005″ to .001″ to ball bearing size, welded, and at the time of the final assembly of the machine lightly touched with a hand reamer.

In the old cast iron slicer a motor bracket, a clamp, seven bolts, nuts, and washers, and ample space were required to locate the motor on the bottom of the machine. In the new design, the motor bracket is completely eliminated. Instead, four studs, simply welded to the side of the machine; four nuts and washers are all that is required to mount the motor in a place that is best suited for the purpose. This arrangement, as well as the fact that the $\frac{3}{16}$″ side plates of the steel slicer proved

to be stronger than the heavier cast iron walls, and, therefore, did not require the reinforcings cast into the old cast iron housing, reduced the base area of the machine by 60 square inches and the weight by more than 30%. The reduction in weight, as well as in space requirement, is much appreciated by every user of slicing equipment.

Another similar saving could be made in providing slides for a tray that collects the crumbs on the bottom of the machine. Previously, two wooden slides were fastened by means of bolts and nuts to the bottom of the housing. Now, two steel strips $3/16''$ by $1/4''$ are welded to the side of the frame. The saving on time and material is obvious.

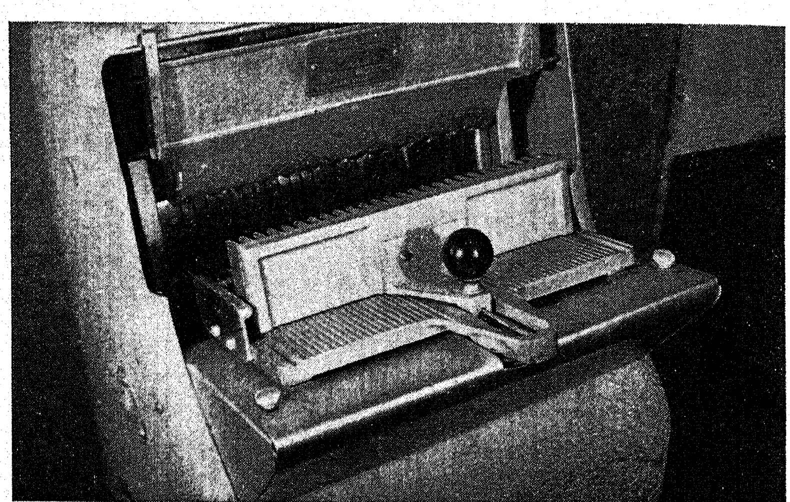


Fig. 6. Bread feeding arrangement of cast iron slicer.

Besides savings of this type, which invariably occur if proper use is made of the advantages offered by welding, the valve of being able to reduce, through welding, the number of bolts, nuts and other separate parts on any machine subjected to vibration cannot be overestimated. Seldom is a machine returned to us without the lack of some screws or bolts; some of which are often essential to the proper operation of the machine.

The bread feeding arrangement of the cast iron slicer, (See Fig. 6), frequently was another source of trouble and complaint. This feeding mechanism on the old slicer was a separate unit attached to the main housing by screws and bolts. This type of construction was dictated by the necessity to hold the machining operations on the cast iron frame to a minimum. An addition of bearings, bosses, and slides on the cast iron housing would have resulted in an increase of machining operations to a point where a profitable sale of the slicer would have been doubtful. This handicap was responsible for a bread pusher that is awkward to operate. Besides, it required easy accessibility from both sides of the machine. The slicer, therefore, had to be placed either at the end of the counter or on a stand.

The above mentioned limitations, however, did not apply to an arc welded design. In the electric arc we found a tool that helped make the feeding mechanism simpler and safer to operate. It made it possible for the operator to remain on one side of the slicer, thereby, saving him quite a few steps in the course of the day. Through links on the inside of the machine the loaf pusher is connected to a handle, (See Fig. 7), which not only is easily and conveniently operated but also removes the hands from the dangerous vicinity of the fast cutting knives. The pusher itself is guided by two stainless steel tracks, formed inexpensively on a punch press and welded to the sides of the slicer frame. Bearings and bosses required to support a system of links and levers were easily provided by parts made on an automatic lathe and welded to the steel frame. In one place, where only a light load is applied, it was found desirable to have a bearing that would not extend through the side plate of the machine. Here, we simply welded a steel bushing to the inside of the frame. An oilless bushing pressed into the steel retainer reduces the friction between the moving parts.

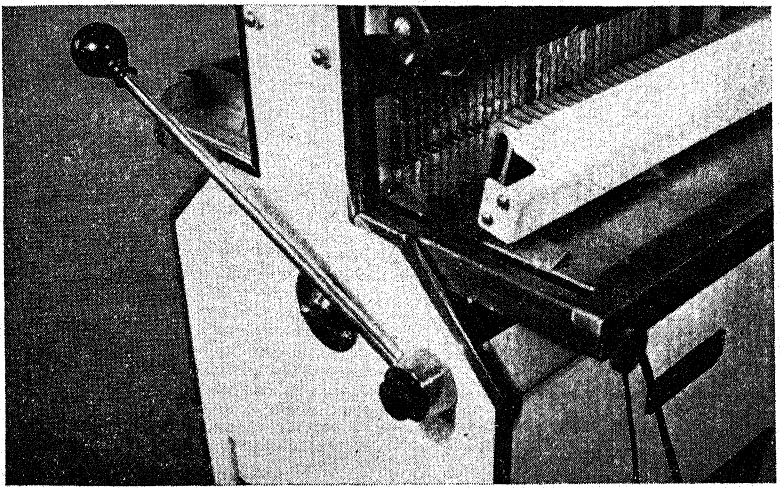


Fig. 7. Bread feeding arrangement of new welded slicer.

In general, it may be said of this particular design, as well as of many other parts that we now manufacture by arc welding, that this new method eliminates the handling and machining of large and bulky parts on big machines operating at slow speeds. Instead, it makes possible the machining of small pieces in small inexpensively operated equipment.

Fig. 8 shows the steel slicer frame just as it left the final welding fixture. Except for a light cleaning from welding slag it does not require any additional machining operations. In this state it is ready for bonderizing and painting.

Thirty-four parts, (See Fig. 9), welded into one solid unit are required to build this frame. The relatively little time that is needed

assembling and welding this unit contradicts the general conception that only those arc welded constructions that are made of few parts are economical. The arc welded knife frames used in this machine are another example of our experience. For the size of frame illustrated in the beginning of this paper, from twenty-nine to fifty-three parts, varying with the thickness of the slice, are required. Still, there is no other method to produce this part at even nearly the same cost.

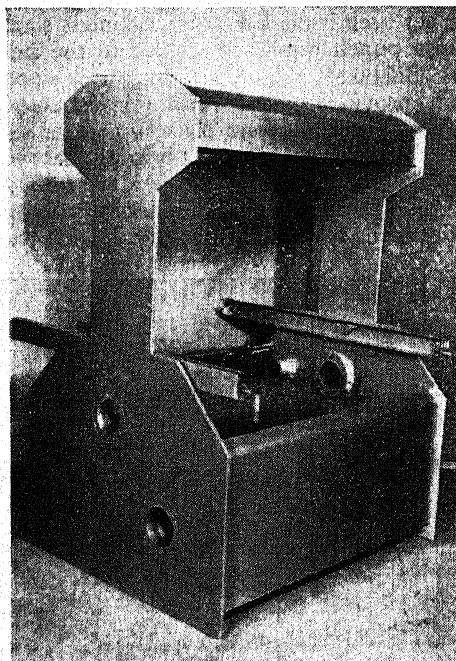


Fig. 8. Arc welded steel bread slicer frame.

Of utmost importance for an economic production of arc welded parts and machines, of course, are means to locate and hold the separate parts while the welding takes place. The number of units that are expected to be made should be the only limiting factor in the design of these fixtures. For the steel housing here described, six fixtures are used. The principal parts of the frame are the two sides, the front and rear plate, and the top cover. To these, in separate jigs, are welded the various parts before the final assembly of all the parts is undertaken.

The two sides, and the front and rear plate are made of $\frac{3}{16}''$ cold rolled steel, while $\frac{1}{8}''$ stock is used for the top cover.

The slicer frames are being built in lots of one hundred. Each operation, beginning with the sub-assembly and welding of the sides, is carried out immediately on all hundred units. The repetition of the same operation and the skill gained by repeating the same movements enables the welder to assemble and weld each unit in little time.

A piece of cold rolled steel 1/4" x 3/8" x 15 1/4", welded to both sides of the frame, is used as a slide for a crumb drawer. To two studs are attached levers for operating the pusher. Ball bearing housings support the rocker shaft. Two stainless steel slides serve as a guide for the loaf pusher and as a rest and support for the stainless steel tables. Two screws are welded into the ends of the tracks. Two cold rolled steel blocks serve to position the tracks. Opposite bearings support part of the pusher arrangement and an automatic safety switch. The large ball bearing housing on the right side of the frame receives the two ball bearings that support the crank assembly. The welding of these parts to the two side plates completes the first welding operation in the construction of this slicer.

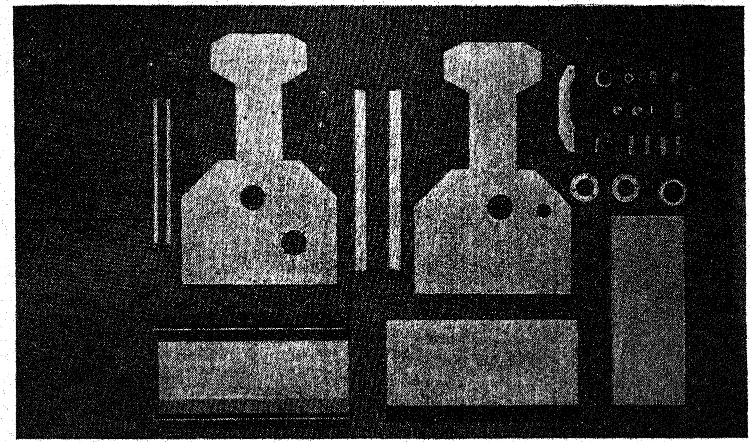


Fig. 9. The 34 parts which compose the arc welded steel frame.

To the front cover are welded four motor studs, the bracket, used in connection with the tray on the bottom of the machine, and a switch bracket. This bracket, for greater accuracy, is attached to the machine at the final assembly.

Attached to the rear cover are a spring clip, made of two parts, and the bracket.

The top cover receives only one part, a cross strip, which is used for providing the upper supports for the two reciprocating knife frames.

The welding of the separate parts completed, the attention is now focused on the final assembly of the frame. While the welding jigs for the parts discussed are merely flat plates designed to locate the various studs and bearings and to assist in keeping the welded units from warping, the final welding fixture has to serve a more difficult purpose. The separation of the welding operations up to this point has made possible the welding in flat position. To obtain the same ease of operation in the final welding of the unit, this last fixture has been made so as to permit rotation around a horizontal as well as a vertical axis. The fixture is easy to operate, requires little handling in locating and clamping the five principal parts and in removing the finished prod-

uct. It produces a housing that is perfectly square and level. This fixture, too, is made entirely of steel, welding being used in its construction to the greatest extent.

The following cost figures are taken from our daily production records. They do not, however, represent the lowest possible factory cost, as several parts are still being made without the help of proper tools. In fact, the first few slicers were built entirely with equipment already in our possession. These served as test machines to prove their utility and as demonstrators to ascertain a demand for so new and different a slicer. Thus, when in the early months of 1937, we were convinced of

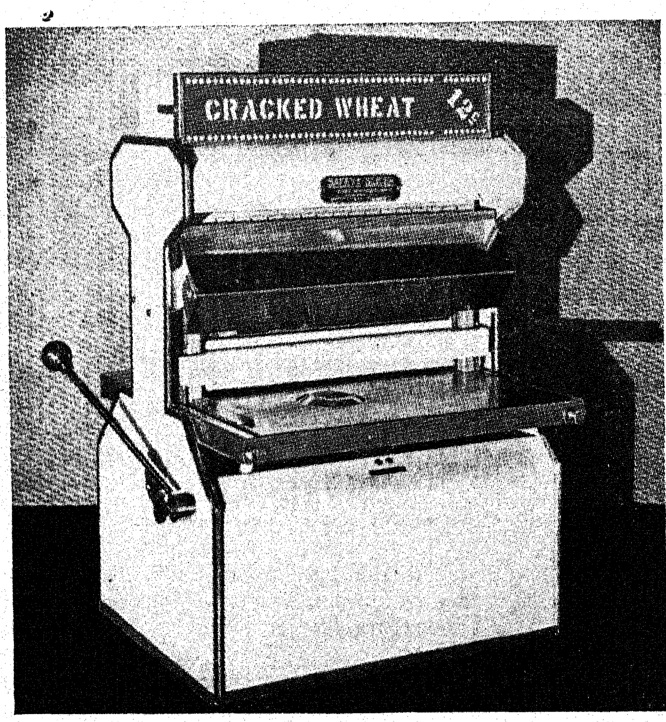


Fig. 10. Modern bread slicer of arc welded construction.

a ready market for a slicer that had proved very satisfactory in its performance, we had little money invested in this enterprise. Arc welding applied in this manner, therefore, reduces the risk involved in the design and manufacture of any new product. As is the rule with all machines that are basically made of cast iron, the original investment in the old cast iron slicer was very high before we had any positive assurance of a return of our investment.

The hourly rate used for computing the labor cost in the production of the steel slicer, as well as the cast iron frame, is set at \$1.55. This is our average cost in the manufacture of our products. It does not, how-

ever, take into consideration that the individual rates charged to more expensive equipment, as boring mills and radial drill presses used in the preparation of the cast iron frame would tend to bring the average cost for the old slicer even higher than the figure arrived at.

From the foregoing cost figures for both slicers, it may be seen that the production cost of the new arc welded steel frame is $4.31, or 30%, lower than that of the old cast iron housing. At the same time, the lower expenditure applied in this new way produces a machine that is very much superior to the old cast iron slicer. This is best proved by a steadily increasing sale of the new machine. (See Fig. 10). Even the current business recession has not interrupted this upward sales curve.

Based on our, and competitors' figures, there are approximately 5000 bread slicers sold yearly in the United States, in Canada, and some in other foreign countries. If arc welding were adopted generally in the manufacture of these slicers, a saving of over $21,000 annually could be made.

This saving, however, should not be limited to bread slicers alone. It may be applied with equal success to many other similar designs. Proof of this are several parts and one machine column, which we have changed recently to arc welded steel at savings as high as 50%.

So firmly have we learned to believe in the superiority of steel construction over cast iron that we are now redesigning another machine used in the food industry; a meat saw, which, so far, has been made of cast iron.

SUMMARY OF COST, ARC WELDED SLICER FRAME

(A)	Material	$ 5.68
	Labor: 1.449 hrs. at 1.55/hrs.	2.25
		$7.93
(B)	Material: (Welding rod)	.12
	Labor: .849 hrs. at 1.55/hrs.	1.32
(C)	Labor: .3 hrs. at 1.55/hrs.	.47
	Bonderizing	.22
	Total	$10.06

SUMMARY OF COST, CAST IRON SLICER FRAME

Material	$ 9.81
Labor: 2.940 hrs. at 1.55 / hr.	4.56
	$14.37

Chapter XXIV—Welded Steel Supporting Structures for Continuous Process Rayon Producing Machines

By R. F. BERGMANN and A. F. MACDONALD,
Chief Engineer, Rayon Machinery Corporation, Cleveland, Ohio, and Designing Engineer, American Bridge Company, Pittsburgh, Pa., respectively.

One of the leading rayon producers in the United States now has under construction an 11,000,000 pound annual capacity plant, which will embody the world's first commercial installation of equipment for the continuous spinning, processing, drying and twisting of high quality viscose rayon yarn for woven fabrics.

The process itself, made possible by an ingenious, highly developed reel composed of chemically resistant molded plastic members, is the result of years of experimental and developmental effort. Continuous spinning and processing of viscose rayon yarn is now considered an accomplished commercial achievement, based on the successful operation of a complete, full-size test or "pilot" machine at one of the company's existing plants.

A wholly owned machinery subsidiary has been organized to refine and commercialize the design, exploit and manufacture or contract for quantity production of machine parts, assemble and erect complete installations both for the parent company as well as all rayon yarn producers, domestic and foreign.

Of the 312,236,000 pounds of rayon yarn produced in the United States in 1937, approximately 75% was accounted for by the viscose process. It remains the lowest cost process yielding a satisfactory yarn, mainly due to the lower cost of the basic raw material and the chemicals used in treating the yarn.

Efforts further to lower the cost of producing viscose yarn by reducing the number of processing steps had previously resulted only in an inferior product, by no means suited to broader distribution. Consequently, further cost reduction together with improvements in quality of product are believed to lie in obtaining the required series of treatments as economically as possible, with a minimum of handling and interruption, and with the greatest uniformity of treatment obtainable.

Fig. 1, presents comparative flow or process diagrams for typical pot spun, spool spun and the new continuously spun and processed viscose rayon yarn.

The adaptability of arc welded steel frame members to the structure required for the continuous machine, and the exceptionally large saving in cost and weight as compared with that of cast and machined members serving the same purpose, is proving a major factor in the economical first cost and commercial development of the process described briefly in the following.

On the conventional pot spinning (centrifugal) machine, viscose is carried down each side by a pipe, through a valve to a small gear or piston pump at each spinning position, then through a unit filter

and, finally, through a tube or "rounder end" to a spinning jet, submerged in the acid bath. The jet has from 40 to 90 small holes through which the viscose is extruded. As the viscose coagulates on leaving the jet and entering the bath, each hole produces a separate and distinct filament of the yarn.

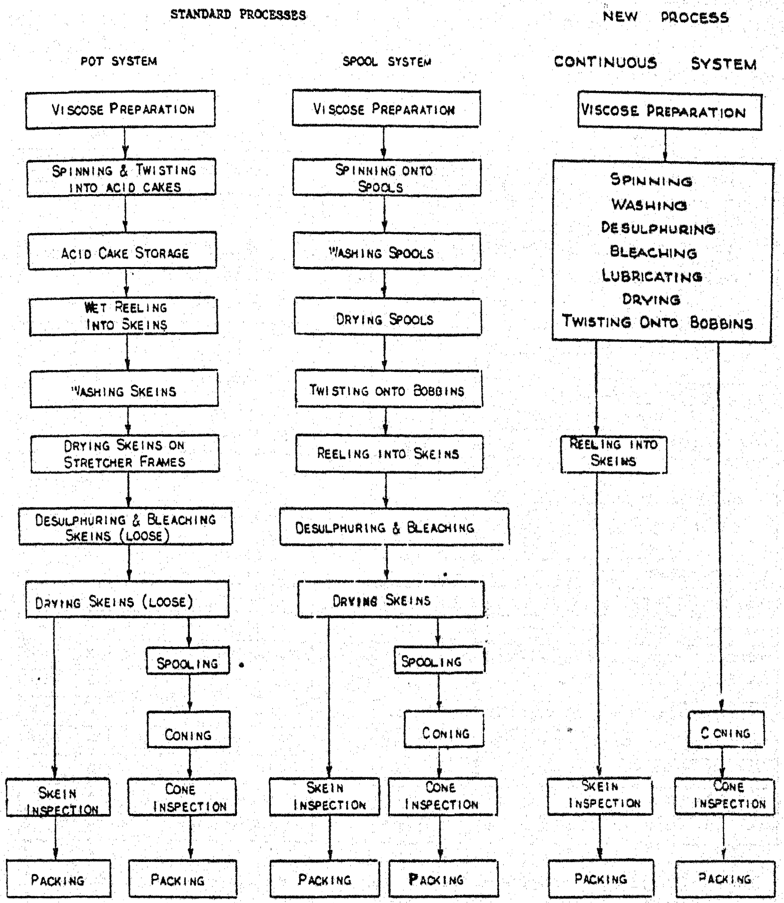


Fig. 1. Comparative flow or process diagrams for typical pot spun, spool spun and the new continuously spun and processed viscose rayon yarn.

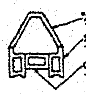
The coagulated yarn is constantly drawn away from the jet, up through the bath, by a glass "godet" roller, independently driven from the geared head of the machine. The pump speed and consequent delivery of viscose and the rotation of the godet, are geared in proper relation to produce a finished yarn of the desired weight per unit of length.

From the godet roller the yarn is fed into the inside of a molded plastic spinning pot. The pot rotates at a speed of 8,000 to 10,000

r.p.m. on a flexible spindle which also carries the rotor of an individual vertical electric motor at each spinning position. A frequency converter is employed to govern the speed of the motors.

The centrifugal force exerted by the yarn against the walls of the revolving pot, together with the traverse motion imparted by a pantograph frame, causes the yarn to build up in the form of an annular ring known in the industry as a cake. The rate of feed of yarn into the pot, in conjunction with the high rotating speed of the pot, causes a twist of 2½ to 3 turns per inch to be put into the yarn.

CAST IRON DESIGN

DESCRIPTION	REQ'D. FOR ONE ASSEMBLY			REQ'D. FOR ONE MACHINE	
	NUMBER OF PARTS	WEIGHT EACH	WEIGHT PER ASS'Y.	NO. OF ASSYS.	WEIGHT
 "A" FRAME	1	660	660		
SAMSONS	2	440	880		
CYLINDER FRAME	1	320	320		
INT. FRAME ASSEMBLY	TOTAL WT.		1860	5	9300#
 "A" FRAME	1	660	660		
SAMSON	1	440	440		
CYLINDER FRAME	1	240	240		
DRIVE SAMSON	1	900	900		
DRIVE END FRAME ASSEMBLY	TOTAL WT.		2240	1	2240#
 PANEL BRKT'S.	2	130	260		
SAMSONS	2	400	800		
CYLINDER FRAME	1	240	240		
INT. FRAME ASSEMBLY-"F"	TOTAL WT.		1300	5	6500#
INT. SPIN FRAMES	1	260	260	5	1300#
DRIVE END SPIN FRAMES	1	600	600	1	600#
PROCESS PANELS	1 / 1	1400 / 2000	3400	10	34000#
TRAVERSE LIFTER BEAM	1	145	145	10	1450#
SPINDLE RAIL BRACKETS	1	25	25	12	300#
PROCESS DECK BRACKETS	1	115	115	12	1380#
SPIN HOOD BRACKETS	1	10	10	10	100#
SPIN APRON BRACKETS	1	30	30	12	360#
TOTAL WEIGHT CAST IRON PARTS PER MACHINE					57,330#

WELDED STEEL DESIGN

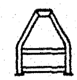
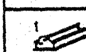
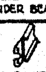
DESCRIPTION	REQ'D. FOR ONE MACHINE		
	NUMBER OF PARTS	WEIGHT EACH	TOTAL
 INT. FRAMES	5	1000	5000#
 DRIVE END FRAMES	1	1450	1450#
 CYLINDER BEARING SUPPORTS	5	170	850#
 ROCKER SHAFT BEAR. SUPPORTS	10	185	1850#
INT. SPIN FRAMES	5	180	900#
DRIVE END SPIN FRAMES	1	400	400#
PROCESS PANELS	10	1130	11300#
TRAVERSE LIFTER BEAM	10	70	700#
SPINDLE RAIL BRACKETS	12	16⅔	200#
PROCESS DECK BRKT'S.	12	25	300#
SPIN HOOD BRACKETS	10	5	50#
SPIN APRON BRACKETS	12	8⅓	100#
TOTAL WEIGHT WELDED STEEL PARTS			23,100#

Fig. 2. Comparative weights of the cast iron and the welded steel construction.

The spool spinning machine is similar in general design to the pot spinner. The spool, located in about the same position as the godet, is usually made of perforated aluminum coated with an acid resisting paint. Leaving the jet, the coagulated yarn is carried up through the bath to a thread guide mounted on a traverse mechanism which lays the yarn evenly on the revolving spool. To compensate for the increasing package diameter as the yarn builds up on the spool, a differential speed control device is incorporated in the spool drive at the geared head of the machine, so as to produce finished yarn of predetermined, uniform weight per unit of length.

Referring again to Fig. 1, if the freshly spun yarn is allowed to dry when restricted in cakes or on spools, it will develop inequalities in its properties depending upon strains to which the yarn is subjected. Further, yarn in any such bundle or package is subject to varying intensity of treatment, both chemical and physical, depending upon which part of the yarn is more exposed.

Such irregularities are minimized by reeling the wet yarn into skeins, which are processed and dried in a loose and free condition. Successive operations listed in the first two columns of Fig. 1 are typical in the manufacture of pot or spool spun viscose yarn for woven fabrics, where quality and uniformity are essential. Each block on the chart represents an operation, and each arrow a handling required to prepare a cone of finished, bleached and twisted yarn ready for the market.

In the spool system, twisting does not take place coincidental with spinning as is true with the centrifugal process. Some form of equipment for twisting as a separate operation is necessary.

The new process combines into one continuous series of operations all steps from spinning to drying and twisting on bobbins, as shown at right in Fig. 1.

This is accomplished by building into one complete machine a simple modification of the spool spinner equipped with continuous reels; a "stepped" inclined processing panel also equipped with continuous reels on which the yarn is chemically treated, washed and dried as it travels from one reel to another down a vertical run; and finally, a cap twister.

The most logical arrangement of combining the several units was to superimpose them for reasons of compactness and economy of floor space, ease of threading when starting or resuming operations on any position, and for the convenient application of the transmission equipment for driving the various operating mechanisms.

The common spin trough serves spinning jets pivoted from both sides. This design permits the narrowest and lightest frame construction believed practical. From this width the machine "builds out" due to the stepped panels on each side to the width required by the number of the reels in a vertical line to complete the processing and drying. The width at the bottom of the panels determines the width of the cap twister.

Commissioned to design and construct 100 complete machines, each with 100 spinning and processing positions, for the parent company's new plant, the machinery subsidiary prepared frame studies and details composed of cast and machined members which conformed quite closely to prevalent textile machine frame practice.

Preference had been expressed by the parent company's officials for rugged and substantial machined cast frame members, to secure accuracy of alignment when erected. This is particularly necessary in view of the extensive amount of long line shafting for driving the various rotating parts. Further, it was expected that with many duplications in members, the castings could be machined by quantity methods and therefore produced at reasonable costs.

The design details were prepared and submitted to many responsible sources for thorough study and competitive quotations. These frame costs were so high that if this method of construction had been used the total cost of the 100 machines would have been substantially beyond the original estimate.

A further careful study of design revealed that even the most resourceful engineering and the most expert manufacture in the foundry and machine shop did not offer any possibility of reducing the total cost of these cast iron parts by more than 25 to 30%. Since this figure was still too high to be considered, it was necessary to look to some other means for securing the frame work at a lower cost.

The drawings covering the cast iron design were, therefore, submitted to a number of steel fabricators for their study and recommendations. They, in cooperation with the engineers of the machinery company developed several designs which were submitted with quotations.

The welded steel design presented in this paper was submitted by the American Bridge Company in competitive bidding with other designs, and was accepted in essentially the same form as herein described.

Fig. 2, shows the comparative weights for cast and arc welded construction. On the basis of the best competitive price quotations, arc welded construction showed a cost saving of over 67%.

On the basis of this design a contract was awarded to the American Bridge Company for all the major parts.

In designing every effort was made to utilize conventional structural steel fabricating facilities for the preparation of the elements making up the completed parts, and to make use of easily obtainable, commercially rolled, structural steel sections.

It is the expectation of the purchaser that this new rayon producing machine will gradually replace existing equipment, and that the expansion of present plants or the building of new plants will require large numbers the same as, or similar to, those now being produced. Because of this prospective volume, the design is especially advantageous, as it makes easily procurable the material and facilities for rapid and economical sources of production.

The design was carefully thought out to facilitate the use of jig welding. This was of prime importance in reproducing at low costs, parts that would be interchangeable and accurate in dimensions. Moreover, since the first contract covered great numbers of like parts, heavy, rigid, permanent jigs were accurately assembled and held while being welded together. These jigs have all been used many times and will be available for future reproduction of parts after those now contracted for are completed.

The intention of the design was to avoid any machining of surfaces for accuracy after the assembly was welded together and removed from the jigs. Except in two parts the necessary accuracy was realized without resorting to machining following the welding.

Before mass production of the major parts of a machine unit was undertaken, experimental sample parts were made and carefully checked. In doing this the accuracy and efficiency of the jigs and production methods were checked.

Much skepticism was expressed as to the practicability of securing the required accuracy by jig welding methods before the experimental parts were made. Many felt that distortions caused by the welding would produce inaccuracies after the pieces were removed from the jigs, particularly in the processing panels. However, these parts have all been produced in multiple, and it has been proven in practice that the distortions caused by the welding were not of sufficient magnitude to interfere with securing the required accuracy by the methods now used.

From the experience gained on this contract it is believed that many types of machine frames and supports, hitherto thought impracticable to fabricate by utilizing welded steel construction, may now be undertaken with confidence.

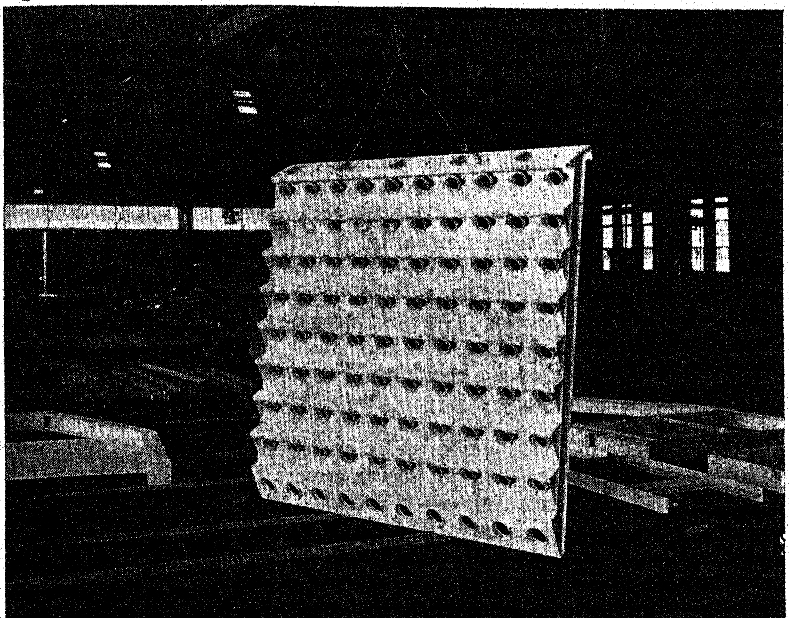


Fig. 3. Process panel, front side.

Process Panel, (See Fig. 3).—Except for the cups and the steel stampings, all elements composing the complete panel are of standard commercially rolled plates or shapes, punched, sheared, bent and sawed with a structural fabricating plant's regular equipment. The cups were blanked and formed into the shapes shown and counterbored and tapped after forming.

Extreme accuracy was required in the alignment of these cups to insure proper operation of the bevel gears driving the reel shafts, which occur at the rear of each cup on the panel. This was secured by assembling in a jig all the parts in consecutive order. Auxiliary fix-

tures in the jig were provided to hold all parts to accurate positions; these parts were then welded together to form a frame from which the cups were entirely free, the cups being firmly attached to plugs in the jig base.

The accurate alignment of the cups is confirmed by a 100% inspection of the panels after completion. Special facilities were designed by the fabricator to produce a marked templet showing the exact location of the axis of each cup. With this equipment two inspectors can check a panel in thirty minutes.

Any cups which are out of alignment are removed and replaced by means of portable jigs provided for the purpose. It has been necessary to remove about 20 cups out of a total of 35,000 of record. This is not difficult to do and proves the practicability of replacement of cups that may get damaged during erection or after the machines are in operation. It was proved in most cases that the cups were misaligned because of improper attaching to the jig, and not due to distortion from the welding.

Each panel contains 356 separate parts, including nuts.

Machinery Box.—These boxes are made up of ordinary commercial plates, bars and rounds. The parts, after the preparation, were assembled in a jig and completely welded together. The welded box was then taken to a horizontal boring mill where all the boring and spot facing was done from one setup, in order to secure the required accuracy. Small pads were machined in this same setup in order to establish accurate gauge points in a plane exactly parallel to the plane of the finished counterbore. The box, after being completely machined, is then assembled with the drive and frame, proper alignment being established by means of the machined gauge pads. Each box contains 30 parts exclusive of bolts.

Drive End Frame.—The frame is made up of ordinary structural plates and shapes. The column sections were bent, milled on bottom ends, and flame-cut to angle on top ends. Bearing plates were carefully pressed and straightened and jig drilled to secure the necessary accuracy.

All the parts were then assembled in a jig in which fixtures were provided for properly holding to position. The bearing plates were attached to machined pads in order to maintain the accurate relation between them and the machinery box.

The completely finished machinery box was then placed in the same jig; it being supported on machined pads in the jig, which registered with the machined bosses or pads on the box. This established the required accurate relation between the plates of the frame and the plane of the counterbore of the box.

All welding was completed before frame was removed from the jig, and no other machining or fabrication was necessary except the drilling of the holes shown in the flanges of the columns. These holes were drilled through an integral drilling templet, gauged accurately to the holes and the center line of the machine.

Each frame is made up of 13 pieces exclusive of machinery box.

Intermediate Frame.—This frame is quite similar to the end drive frame previously described. It is assembled in the same jig as was used for the end drive frame, and similar methods were employed. Each frame is made up of ordinary structural steel plates and shapes, numbering 10 exclusive of nuts.

Intermediate Spin Frame.—These frames are made up of structural steel shapes and plates, the elements being pre-fabricated and then welded in an assembling jig. No unusual methods were necessary. The frame required no machinery or other fabrication after its removal from the jig. Each frame is made up of nine pieces.

Drive End Spin Frame.—The parts for these frames, made up of structural plates and bars, were pre-fabricated and welded together in a jig. Because of the accurate relations required for the connections of large mechanical units, the fabricator elected to machine the pads and the bases after the frame was removed from the jig.

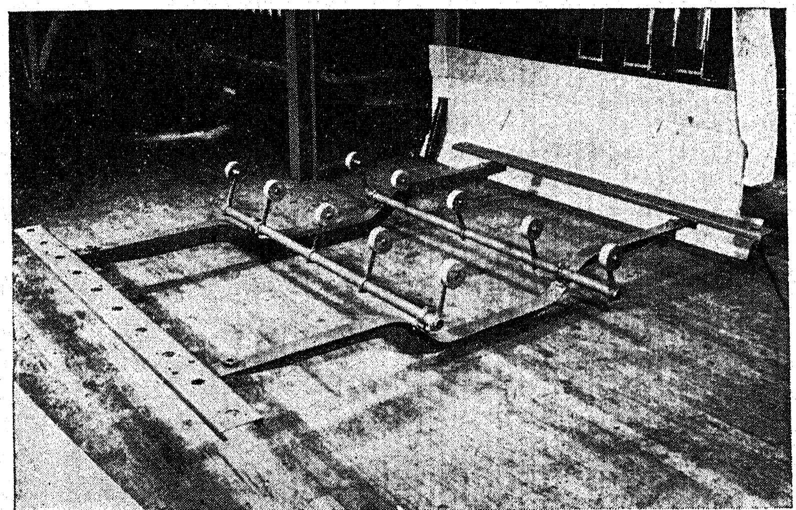


Fig. 4. Detail of twister traverse table.

Traverse Lifter Beam.—These beams comprise the two cross members for each traverse table of the cap twister, five such tables like that shown in Fig. 4 are provided on each 100-end machine.

The traverse lifter beam is made of structural shapes and two pieces of mechanical tubing for the vertical guide rod bushings. By using this accurate tubing it was possible to jig-weld all parts together, after pre-fabricating, and to avoid any drilling or boring after piece was removed from the jig.

The weight of the welded steel beam is less than one-half the weight of the corresponding cast iron member, an important advantage in the operation of the reciprocating or traversing table for winding the bobbins of finished yarn. The five tables, 44 feet long, supporting 100

spindles and bobbins, are counterweighted and suspended by pulleys and chains from the longitudinal rocker shafts on each side of the twister, and operated from a cam at the drive end of the machine.

Miscellaneous Parts.—These parts offer no unusual features, but are interesting adaptations of welded steel construction, making effective use or ordinary structural steel plates, bars and shapes.

All welding for all parts described by this paper was done by the shielded, manual metal-arc process, as covered by American Welding Society Specifications No. A1.

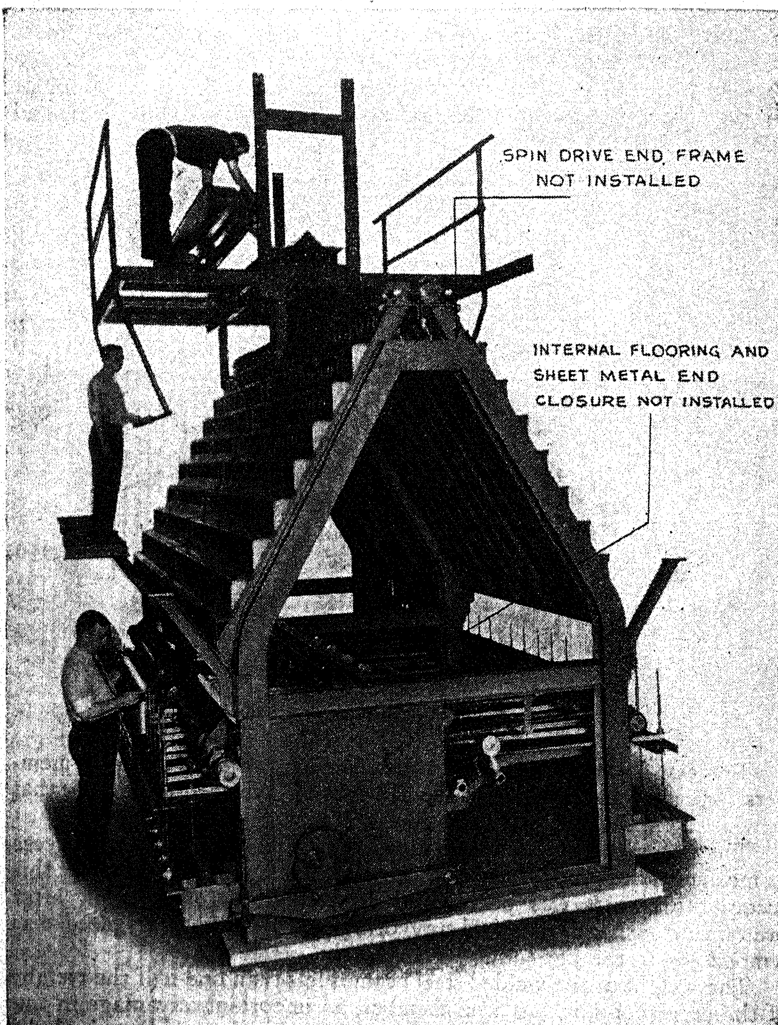


Fig. 5. Shop assembly, two sections of machine frame.

Comment on Welded Steel Design.—The weights in Fig. 2 include all frame members of each of the two designs which are comparable. Other items such as spin transmission beams, walkways and flooring, and spin trough steel are adaptable to either the cast iron or the welded steel machine frames, and are therefore not included in any comparison.

The estimated annual production from the 100 machines is 11,000,000 lbs. of finished viscose yarn. A common unit of evaluation in the industry is:

$$\frac{\text{Property, plant and equipment investment,}}{\text{Pounds of yarn produced per year}} \text{ generally from \$1.00 to \$1.10}$$

The net saving in the installed cost of equipment producing 11,000,000 lbs. annually, is about 3.1% or 3.1 cents.

If, for other reasons such as processing and handling economies, improvement in quality and uniformity of product as heretofore stated, this process were in time applied to the entire viscose rayon industry, the approximate saving in first installation cost measured as above would be:

240,000,000 (estimated lbs./year) x 3.1¢, or $7,440,000.00.

Until the large scale, commercial operation of the plant now under construction has had a reasonable length of time to demonstrate its performance, no accurate evalution of the increased efficiency and economy of this process can be made. However, all possible cost objections to superimposing the processing units into the composite structure

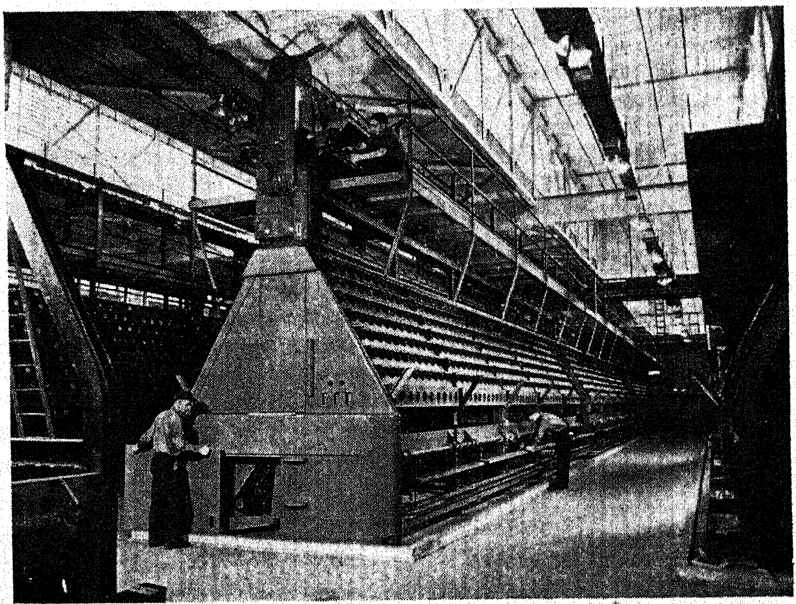


Fig. 6. One of the arc weldea continuous process rayon producing machines during construction.

have been eliminated by the economy and simplicity of the welded frame.

Moreover, it is significant that the processing and handling expense saved, the greater uniformity and high quality of the viscose yarn produced on the pilot installation now made practical by this structure, have satisfied the parent company's management as to the soundness of their investing over eleven million dollars in the new plant to be equipped solely for this process.

The designs in welded steel were prepared by the successful bidder during May and June, 1937. Contract for 100 complete machine assemblies was awarded in July, 1937, and preparation of shop drawings and jigs started promptly thereafter.

Erection of the machine frames began in June, 1938. Fig. 5 shows assembly of two sections of machine frame. A view of one of the machines during construction is shown in Fig. 6.

Chapter XXV—The Future of Arc Welding in the Cutting Industries

By Adolph V. Bulaw,
Vice President, Bulaw Welding Co., Chicago, Ill.

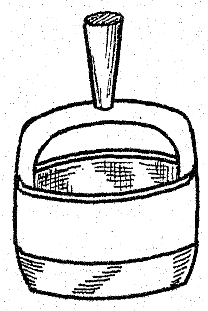
It is a known fact that arc welding has been of immeasurable value to innumerable old industries and is rapidly proving its worth to many new ones. However, when a comparatively young industry, such as the powder puff industry, is mentioned, the thought of arc welding appears very remote. The words "powder puff" automatically imply soft, dainty, pleasingly scented velour discs and arc welding seems to have no place in the picture. Yet, it is inevitable that arc welding is destined to become an attached function of the manufacturing process Not only has it shown its profit-making ability in the powder puff industry, but it is destined, eventually, to revolutionize all cutting industries. Cutting is the principal operation of many industries. The word "cutting" is a term associated with several different industries that cut out non-metallic materials such as cloth, leather, paper, cork, cellophane, rubber, and various synthetic compositions, in which a very sharp knife-like edge is employed in some form or other.

A study of previous methods employed in the cutting of powder puffs will be used as a comparative basis, showing similarity to many other industries using the cutting process for other materials. Clothing manufacturers, glove makers, shoe makers and many others have passed through the same stages of advancement as the powder puff industry. Some industries using cutting have advanced rapidly while others have lagged behind. The great majority of powder puff manufacturers are very far behind. There has been very little experimenting. A very limited few have kept abreast with the latest advancements. The new ideas that have developed are naturally kept secret from competitors. Manufacturers have had to rely on die makers for new ideas, and very few die makers have cared to study the problem. Die making is a highly skilled craft yet, as a general class, die makers are very reluctant to accept new methods and ideas. For this reason, arc welding has been used sparingly in their industry to the present time.

Enterprising manufacturers, possessing initiative, knowing something of the many advantages of welding, have been forced to consult specialized job shops rather than die makers to execute their ideas involving welding. Development of cutting in the powder puff industry has been slow because of that fact.

The early stage was the method of cutting with hand scissors or shears. The output per operator was meager, but at that time the demand was small. The great waste involved by this method was absorbed by the selling price. As slow and wasteful a method as it was, it lasted several years.

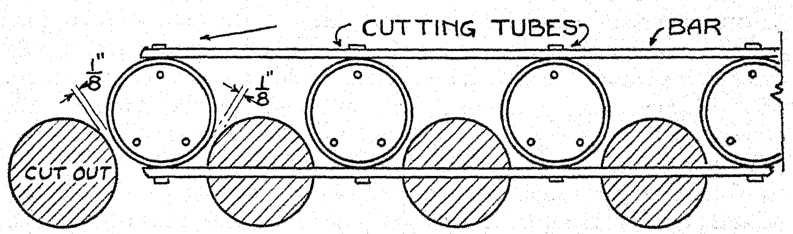
Following the World war, feminine interest in cosmetics gained considerable momentum. The demand for the little cloth discs was growing rapidly and the almost-primitive hand scissor method was doomed to go. It was much too slow and the waste of material totaled almost 25 per cent. No close size or standardized uniformity could be maintained. To overcome most of these disadvantages, a forged round steel tube offered the best solution. The entire tool being a comparatively simple idea, and very inexpensive, soon revolutionized the entire industry. The single tube hand mallet cutting die consists of a forged tube of the desired diameter with a chisel fastened to the top. No "expellor" or "kicker" arrangement is used for expelling the cloth after each cut. The operator merely strikes the die with a heavy mallet through two layers of cloth until the die fills, and then removes them by pushing them out of the bottom by hand.



Output and production by this method was increased many times over the old method. The waste was still considerable but only a fractional part of what it was before. Even as crude and unproductive a method as it may appear, to this day it still finds extensive use. The largest manufacturer of powder puffs still uses this form of cutting exclusively. This stage of advancement is the stopping point for over 90 per cent of the powder puff manufacturers in this country. In order for these manufacturers who have lagged behind to compete with manufacturers who have brought down prices by using less wasteful and more productive methods, labor has had to absorb the difference in lower wages.

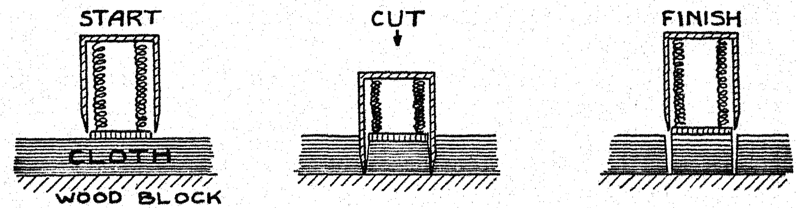
After several manufacturers had tried to overcome the waste of material involved and the time lost in placement of the single-tube die, one manufacturer finally hit upon a simple idea that solved the problem to a very great extent. It was an elaboration of the single tube mallet cutter. Instead of cutting with one tube at a time, several single tubes were fastened to a strong bar, enabling one operator to cut with ten or twelve tubes at a time. Instead of striking the die with a mallet, a toggle action envelope press is used. Only a few of the more enterprising manufacturers could foresee a return on their investment for new presses and new dies by replacing their hand mallet method with this new one. Through the use of a press, twelve layers of cloth are cut instead of two. The waste of material decreased because the dis-

tance between tube placement could be held to very close limits. In handling the gang die, the operator shifts it from side to side after each cut in a zig-zag manner to get the greatest output with the least waste. Instead of filling the die with cuts and then pushing them out

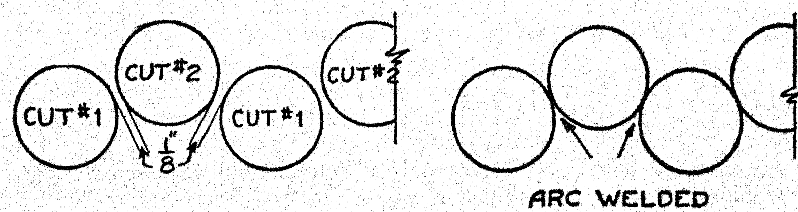


(Top view to show shifting method used)

by hand, as in the single-tube method, an expellor arrangement is used in each tube, causing the cut pieces to remain on the cutting block. After the block is filled with cuts, the operator places them in boxes.



It was found that, in order to cut twelve layers of cloth at a time, an allowance of one-eighth of an inch was necessary between cuts, an increase of about one-sixteenth over the hand mallet method. The die has a tendency to slip into the previous cut unless an allowance is made. With mass production of the straight gang die, running the output per man to almost one-half million puffs per month, that necessary one-eighth inch allowance meant a lot of waste. The shifting of the "straight in line" single tube gang die from side to side from one cut to the next induced the idea of making dies with tubes joined in a staggered gang. By making the cutting edges tangent and using one part of the cutting edge common to two tubes, the one-eighth allowance between tubes has been salvaged. In order to obtain this great saving, many problems were encountered.



The first "staggered" gang die cutters were machined out of a solid block. Needless to say, the dies were very expensive and clumsy. They did prove practical, and the initial cost became insignificant when the time and material saved per year were totaled. To get around the great amount of expensive machining, the oxy-acetylene welding torch was eventually brought into use to weld forged tubing together. The resulting saving of constructing a die by welding was a substantial one. Extra heavy material was used at first because in welding the tubes together close alignment was impossible due to the unusual contraction and warpage taking place. The inside of the tubes had to be machined into their proper place, the oversized material allowing for machining. The maximum number of tubes was ten. Beyond that number, the distortion during welding increased beyond practical control. Hardening of the cutters had been impractical because the resulting warpage and bowing was beyond repair. Bulkiness was relied on for strength of the cutting edge. An average ten-tube die weighting nearly forty pounds, and lifting that weight several inches with the arms held in a horizontal position, brought on a problem of physical fatigue. Die makers have to this day relied on the oxy-acetylene process for welding the tubes together.

By entirely replacing the oxy-acetylene method of fabrication with that of arc welding, lighter, longer, stronger and less expensive dies are now possible. The method used in making the illustrated hexagon powder puff die entirely with the use of arc welding can just as well be extended for the making of dies used for cutting any symmetrical shape of any non-metallic material.

Being known as a job shop specializing in the welding and repairing of tools and dies, we were duly called upon by one of the largest and most enterprising powder puff manufacturers in the middle west to design and make a "staggered gang die cutter" to cut across a thirty-six inch width of cloth. The die was to cut a new type of powder puff that was sweeping the country by storm. The simplicity and low cost of manufacturing was expected to warrant their discard following one or two applications of powder. One dozen retail for ten cents. The cuts were to be of two and one-half inch true hexagon shape.

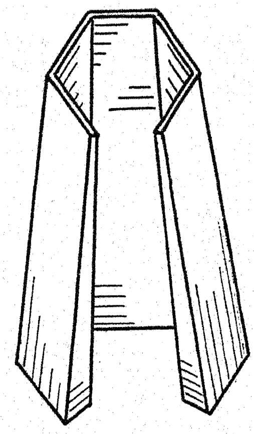
The difficult problem was that the die required 23 tubes, almost two and one-half times more tubes than the staggered gang dies made up to that time. In order to cut through twelve layers of the soft blanket material, a light wall structure had to be employed, on the same principle as used in the single-tube gang die. Without the usual bulky edge for strength, the die had to be hardened. The single tubes as used in the straight-gang die have been oil hardened before assembling.

At first it looked like an impossible task. Following extensive study, it was determined that to make a die of so many tubes would be a very difficult job to control if the previous method of construction were to be used. A total of 385 inches of welding would be required in the construction, each joint being welded at an angle. The electric arc welding method was definitely the only practical method to employ.

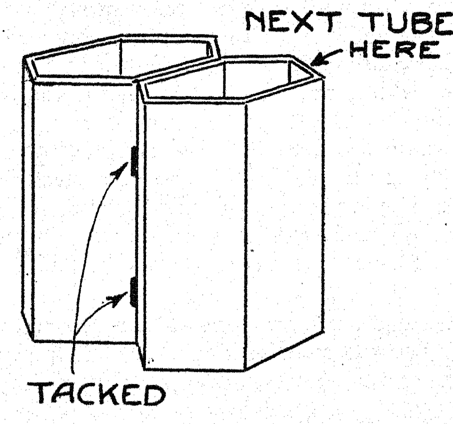
The problem of selecting the proper steel was very important. Following a study, it was found that chrome-molybdenum tool steel would be the best suited because of its great tensile strength and air hardening qualities. The welding rod selected for welding the joints between the tubes had to be of unusual tensile strength in order to stand the continuous great strain the die would be subjected to in use. It also had to weld readily to the chrome-molybdenum steel. The rod best suited was one made by a well known manufacturer for welding high tensile steel. Its deep penetration qualities and non-porous welds, combined with unusual tensile strength, make it the best adapted rod to use on die steels.

For the cutting edge itself, an electrode was selected for its tough, non-porous weld. The rod contains chrome and molybdenum and, by mixing with die steel, it retains its air-hardening qualities very well.

Fabrication.—Following computation and calculation, a drawing is made of the cutting edge on paper. After the drawing is checked for clearance and position, a template is made on sheet metal and cut out. The steel bars are cut to length ready for forging the tubes. The first tube is forged as a completed hexagon with the aid of a hexagon bar, and welded together at the seam. The remainder of the tubes are forged complete, less one side.



One tube is clamped to a surface bench next to the full hexagon tube, and is checked with the template to see if it is in the proper position.



The two tubes are tack welded together.

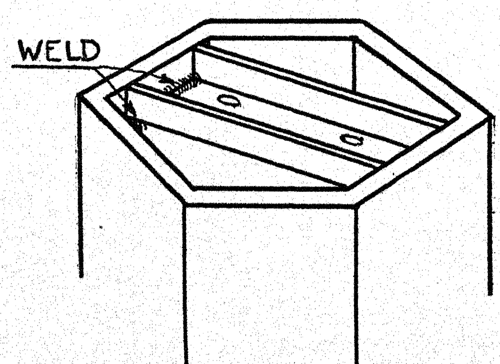
After removing them from the surface bench, two deep penetrating beads are welded on the inside, staying one-half inch above the cutting edge.

A fillet is welded on the two outside seams for the full length of the tube except for one-half inch below the cutting edge.

The one-half inch cutting edge portion that was purposely left unwelded is next welded. The third tube is clamped on the surface bench with the two welded tubes and lined up very closely according to the template and tacked as before. The third tube is welded to the second just as the second was welded to the first. This procedure is repeated until all 23 tubes are welded together.

Two handles are welded on each end of the die to facilitate handling during cutting.

One and one-quarter inch channel pieces are fitted flush to the top of the die for supporting the expellors, and are arc welded from the inside of the tube.



The entire die is annealed in order to relieve the welding strains and soften the joints so they may be machined. A sheet of asbestos paper is placed on the surface bench and the red hot annealed die is

clamped very securely to the bench with the cutting edge on the asbestos so as to straighten any bow present due to welding. It is heavily covered with asbestos and allowed to cool overnight.

After cooling the die is ground parallel, making sure that all low spots on the cutting edge clear up.

The bottom edge is painted with copper sulphate. The cutting edge outline is scratched on the die with the aid of the template.

Next the inside is ground and filed to the scratched mark. The outside is brought to a knife-like edge with the use of Bakelite wheel on a flexible shaft. The razor edge sharpness is brought on with the use of sanding drums, also on a flexible shaft.

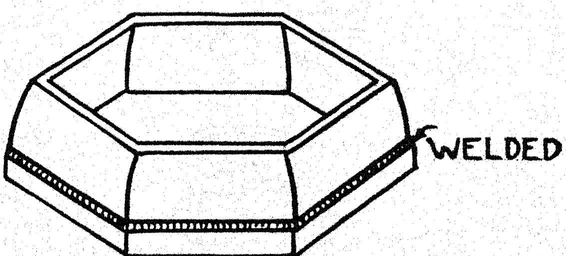
Since chrome-molybdenum is an air-hardening steel with unusual toughness even in its annealed condition, only the cutting edge is hardened. The entire cutting edge is air-hardened with the use of an oxy-acetylene torch. About one-eighth of the cutting edge is heated with the hot cone as rapidly as possible.

The larger mass of metal below the cutting edge almost instantly absorbs the heat from the edge. An electric blower is used right behind the flame to help cool the steel. The cooling rate is rapid enough to produce a hardness on the cutting edge ranging from 50 to 60 Rockwell "C".

The bluish color is next removed by polishing the edge.

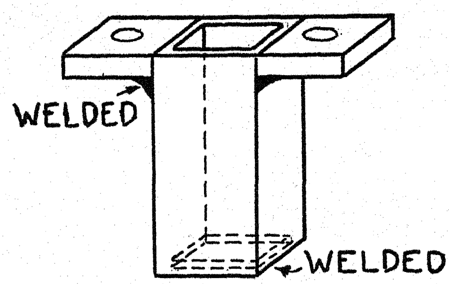
A coat of aluminum paint is applied.

The expellors are a new idea and show a very good application of welding. The expellor is the unit with the spring forcing the plate to stay out and forcing the cut pieces to stay on the block after cutting. The expellors are designed to lift the die above the cloth after each cut. To do that, the expellor must protrude past the cutting edge by five thirty-seconds or three-sixteenths of an inch. If the expellor plate was thick enough to be in the tube and still protrude that far, the weight would be considerably increased. To save the weight, $\frac{1}{8}$ inch plates were cut out in hexagon shapes in order to fit in the tubes and collars cut from a thin tubing and formed to hexagons shaped on a bar were welded on the outside.

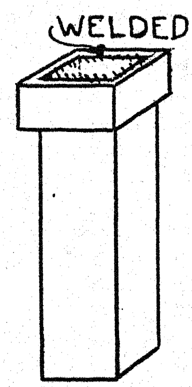


To keep the expellor plate always in the right position, square tubing and shafting were used. After all the material is cut, the $\frac{1}{8}$ inch square collar is welded flush into one end of the square tubing.

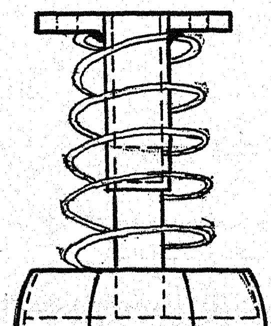
Two one-quarter inch stove bolt nuts are welded to the opposite ends of the tubes.



A one-quarter inch collar is welded to a shaft to slide inside the tube.



Holes are drilled through the channel iron for placing the stove bolts through to hold the expellor assembly. The shaft is placed inside the tube and mounted into the die. The die is then chimmed up to one-eighth inch above the surface bench and the plates are located in their proper position in the tube and tacked to the square shaft. The entire assembly is removed from the die and welded.



A light spring is wound on and the assembly is painted. The expellors are replaced in the die and it is ready for operation. The complete arc welded die is shown in Fig. 1.

Comparisons.—In using a basis for comparing the savings that have resulted through the use of this new die, it will be compared to the die it has replaced, namely an 8-tube straight-in-line gang die. The

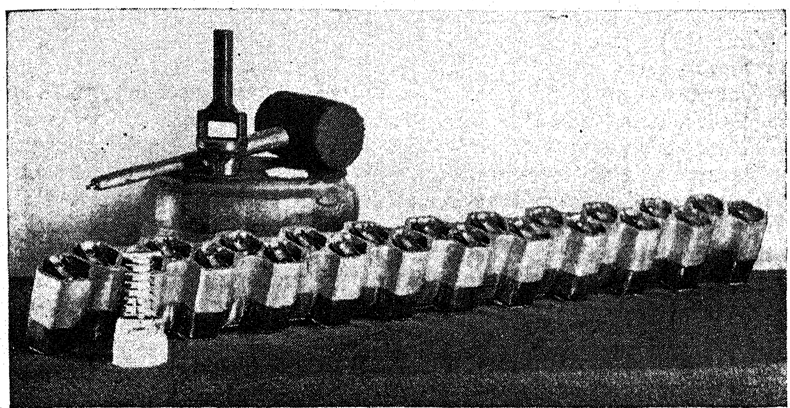


Fig. 1. Top view of 23-tube arc welded staggered gang powder puff cutting die and single-tube hand mallet die. Expellor unit with cut puffs in foreground.

other industries are using the straight die method very extensively but it must be remembered that only a few powder puff manufacturers have advanced thus far. To compare the new die with the hand mallet die would only produce very fantastic results.

Similarity of the two methods:

1. The staggered die cuts 12 layers of double blanket material just as the straight-in-line die.
2. The time required for locating and placing the die for each cut is the same in both cases.
3. The time required for the press to force the die through the cloth is also the same in both cases. For ease of computation the time will be standardized at one cut per minute, only a slight deviation from the actual.

Output of Labor

	8-Tube Straight-in-Line Gang Die	23-Tube Staggered Die
Number layers of cloth cut	12	12
Number cuts made per minute	1	1
Number pieces cut per stroke	96	276
Number of pieces cut per minute	96	276
Number pieces cut per hour	5,760	16,560
Number pieces cut per 8-hour day	46,080	132,480
Number pieces cut per 40-hour week	230,400	662,400

It would require 115 hours, or almost three weeks' time, to cut what the 23-tube die cuts in one week. The actual saving of time is 75 hours per week, and figuring that at 50 cents per hour, the direct labor saving amounts to $37.50. If that were to be extended to take in a year's time, a saving of $1,950 would be the result of labor alone.

The saving in cloth that became possible through the use of a staggered gang die is even greater. In operating the single-tube gang die, an allowance of 1/8 inch is necessary between each cut. Adding up these one-eighth inches between tubes for 36 inch width, the total is close to three inches ($23'' \times 1/8 = 2.875$).

That means the die could have been almost 3 inches shorter in overall length had each tube been moved in 1/8 inch for each tube. To be conservative, let us say there would really be only a two-inch saving. In cutting through 12 layers, that means that 12 one-yard strips each 2 inches wide are saved per every yard cut, or a total of 2/3 yards. Figuring material very conservatively at 60 cents per yard, for the 2/3 yard saving per yard cut, a material saving of 40 cents ($.60 \times 2/3 = .40$) results. Cutting an average of 275 surface yards of material per week with the new die, a saving of $110.00 accrues.

Without even considering the other savings taking place, such as the saving of electric power, derived through using the machine only one third of the time to cut the same number of puffs, a saving of

Labor	$ 37.50
Material	110.00
	$147.50 per week

results through the use of this new type of die. It must be remembered that this is in comparison to the single-tube gang die. To compare with the single tube hand die, the amounts become seemingly unreal.

A hand cutter, cutting at the rate of a stroke every three seconds, would cut 40 pieces a minute, or 240 an hour. Comparing just pieces cut per hour, we have 240, as compared to 5,760 with the single-tube gang die, as compared to 16,560 with this 23-tube staggered die. In ratios, the straight gang die is 24 times faster and the staggered die is 69 times faster than the hand method.

This principle is adaptable to practically any shape of cut in any cutting field of non-metallic material, such as the cutting of leather, paper, cellophane, rubber, cork and others.

Comparison of the costs of constructing the three different dies shows about the same per tube. A single tube hand cutter of this size would cost approximately $7.00. An 8-tube straight-in-line gang die costs $66.00, as compared to the 23 tube die which was sold for $276.00. The 8-tube straight die can earn its investment back in less than a day when compared to the hand cutter. The staggered die can earn back its cost in two weeks' time when compared with the single-tube gang die.

Life of the die is infinite with proper care. There is nothing to ever wear out. If the cutting edge becomes dull, after several years of use, it can easily be re-sharpened to razor sharpness for approximately $10.00.

In case of an accident to cause a chip or a crack in the cutting edge, the section can be re-built perfectly without causing an undercut on each side of the weld.

The method employed for doing that is a secret technique developed by our company. It is very definitely possible and is the backbone of our business.

Through the savings derived from the use of this improved method, the manufacturer is able to make a greater profit. The public benefits in many ways. By reducing the selling cost to the point where powder puffs no longer are an expensive luxury, more are used. Instead of washing soiled powder puffs, the price now warrants their discard following one or two uses.

Arc welding has thus pioneered into a new field. Its limits of application in the construction of gang cutting dies are boundless. The surface has only been scratched.

Chapter XXVI—Platen Press Frames Arc Welded

By LLOYD A. WHITAKER,
Chief engineer, Thomson National Press Co., Franklin, Mass.

The company with which the author is connected makes various sizes of heavy duty cutting and creasing platen presses for box work and cut out specialties and quite often we are asked to quote on a press of a size larger than we make.

Such a press will require a new frame, new gear wheels, guards, platens, etc., which will all require new patterns, and if we plan on mak-

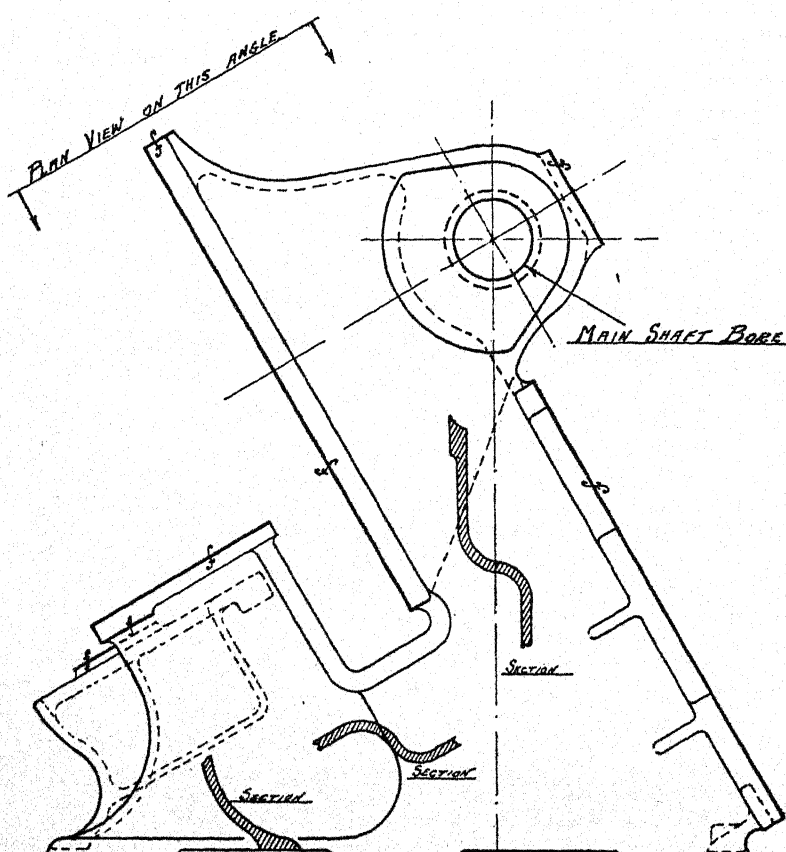


Fig. 1. Side view cast iron platen press frame.

ing them in our own shop, the time involved in pattern work is so great that the prospective purchaser cannot wait for the machine.

On the other hand, if the patterns are made by a commercial shop the cost will be much higher and a great deal of time is still necessary.

The main item in both time and expense, is the pattern for the frame. These frames weigh several tons and are one-piece castings with the inside hollow except in the area where the cutting force is exerted. This area is ribbed for strength and to cut down weight. As a result, the core boxes involve more work and are more costly than the pattern itself.

With an extremely large machine the field in which it may be used is comparatively limited and we must necessarily pro-rate the pattern cost over the number of presses we may expect to sell. These pattern costs can easily be two or three thousand dollars and if we estimate that we will sell three or four of these odd size presses the cost must be distributed in that proportion.

From experience, we would allow a month for designing and drafting before any pattern work could be started. Six or eight weeks would

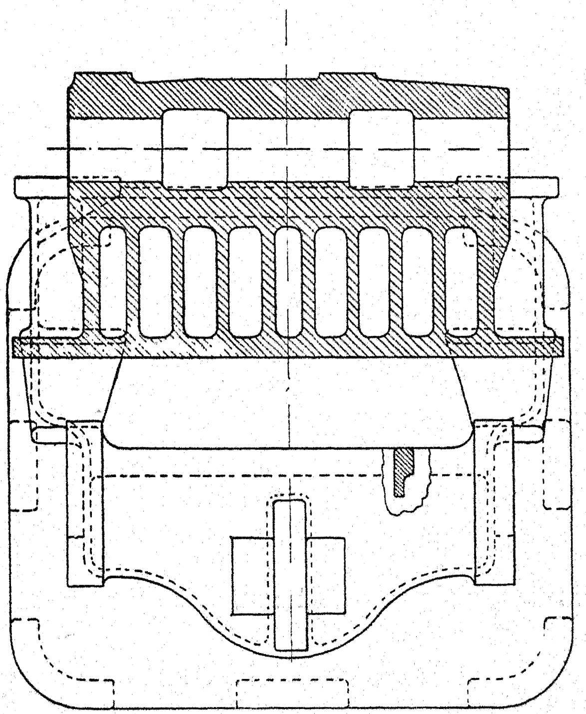


Fig. 2. Plan view cast iron frame.

be necessary to make the patterns and the frame itself would require two weeks for moulding. Also, an additional eight or ten weeks would be necessary for machining, painting and assembly.

This makes the total time to complete the press very close to six

months, which is a period of time that very few companies, making a seasonal product, can afford to wait for delivery.

Since the frame alone accounts for so much time and expense, we have consulted engineers of the leading commercial welders regarding the feasibility of fabricating these frames of sheet steel to save time and pattern cost.

For experimental purposes, we have had a frame for one of our smaller machines fabricated by them and although not yet completed

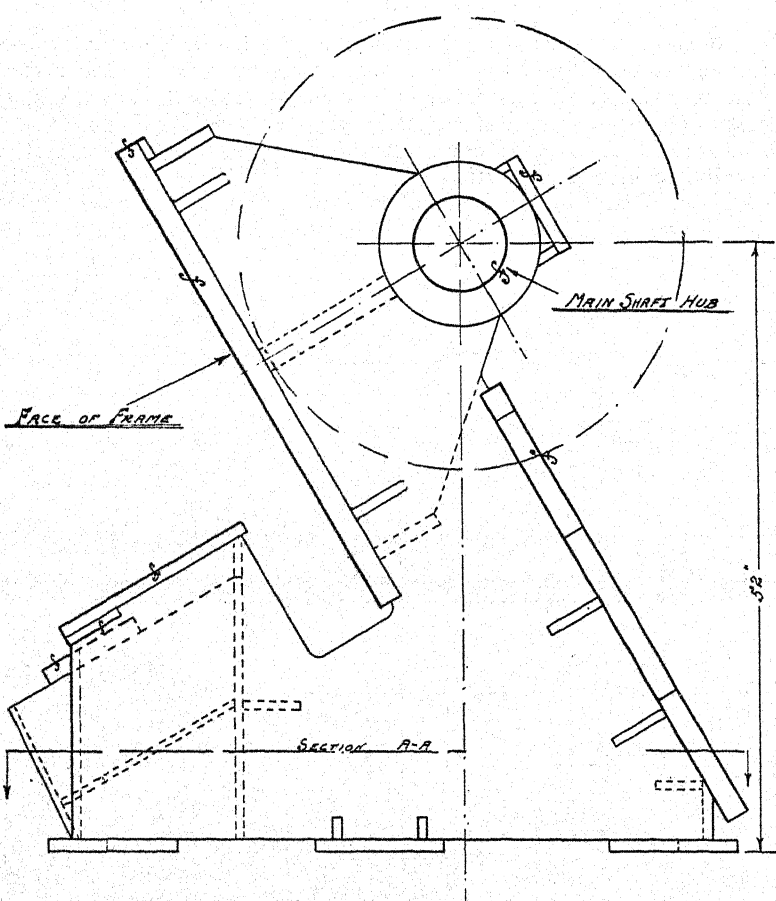


Fig. 3. Side view arc welded steel frame.

we have made several test cuts and find it extremely rigid and of course, much lighter in weight.

It is our intention to eventually equip ourselves to fabricate these frames and in this paper I will show how a frame made of welded construction can be made stronger, lighter in weight, more economically and in much less time than one, for which we now have patterns and

are at present having made of cast iron. This press has recently been redesigned for welded construction and, since we know the present cost and weight of the cast iron frame, very definite figures can be used in the comparison.

Figs. 1 and 2 show the side and plan views respectively of the present cast iron frame for our largest 38″ x 54″ cutting and creasing press. These figures have been drawn ⅛ actual size but show quite clearly the contour of the frame, the arrangement of the bosses and ribs and bear out the statement concerning the complicated system of coring. The bulk of metal surrounding the main shaft quite often causes cooling cracks, and while rejected frames do not involve any expense to us they can disrupt a shipping schedule.

Figs. 3 and 4 show the same frame made by fabricating and are side and plan views.

For welding purposes, the main shaft hub would be a steel casting

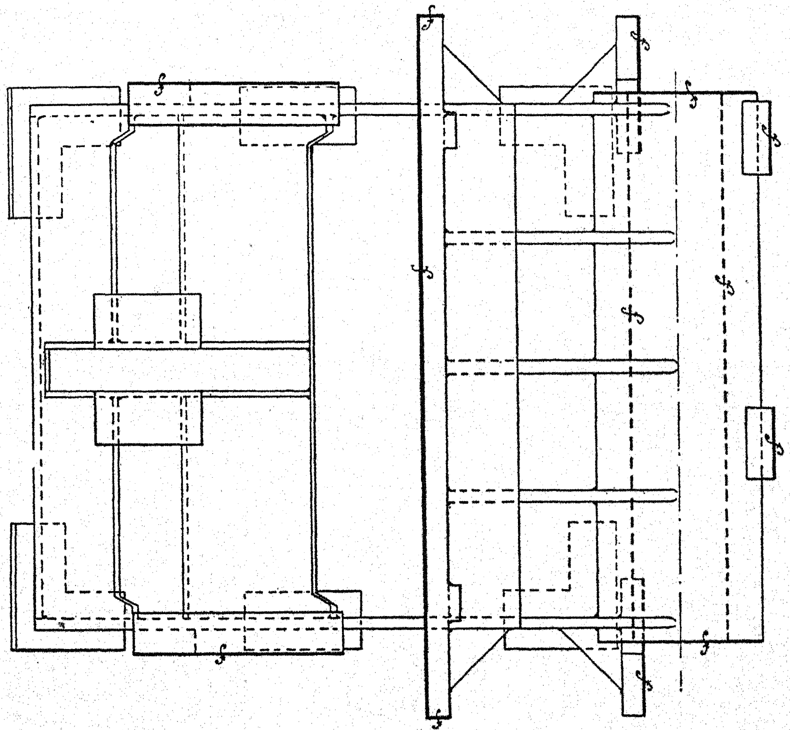


Fig. 4. Plan view arc welded steel frame.

turned inside and outside and this turning should relieve any casting stresses and also provide a clean and smooth surface to which we would weld the side frames and center ribs.

The general appearance of the welded frame is not much different from that of the cast iron. The most noticeable difference is the absence of the fancy curves which have always been on the castings and

were primarily to provide draft for the pattern in moulding and had no utility otherwise.

Since there is no need to maintain these shapes in welded construction, I have laid out this frame to use all straight surfaces and the frame adapts itself very easily to this type of design.

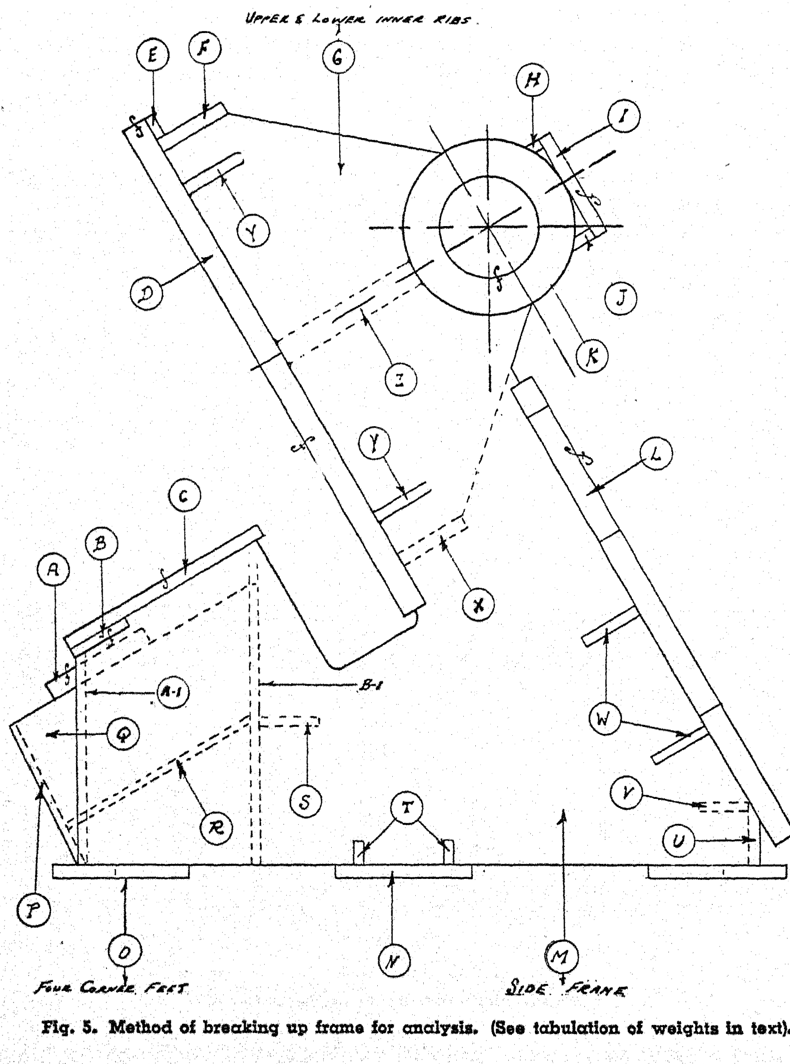


Fig. 5. Method of breaking up frame for analysis. (See tabulation of weights in text).

The two outside surfaces have been made of 1″ stock and, while they could be of lighter material and still be sufficiently strong and rigid, there seems to be a tendency in steel construction, especially when the machine is gear driven, for the large sections to act as a sounding board and magnify the noise of the gears. For this reason alone I have

TABULATION OF MATERIAL WEIGHTS

(See Fig. 5)

Segment No.	Number Required	Unit Volume Cubic Inches	Unit Weight Lbs.	Total Weight Lbs.
A	2	50.4	14.1	28.2
B	2	7.8	2.1	4.2
C	2	63	17.6	35.2
D	1	5300	1484	1484
E	2	4.5	1.26	2.52
F	1	263	73.8	73.8
G	6	222	62	372
H	2	4.5	1.26	2.52
I	2	67.5	18.9	37.8
J	2	9	2.52	5.04
K	1	4770	1338	1338
L	2	620	173.5	347
M	2	2156	602.6	1205.2
N	2	55	15.4	30.8
O	4	85	23.8	95.2
P	1	22.9	6.14	6.14
Q	2	149	41.7	83.4
R	1	30.4	8.5	8.5
S	1	157	44	44
T	4	1.9	.55	2.2
U	1	142	39.8	39.8
V	1	83.5	23.4	23.4
W	4	14.5	4.05	16.2
X	1	252	70.5	70.5
Y	4	9.3	2.6	10.4
Z	1	1071	300	300
A-1	2	210	59	118
B-1	1	714	200	200
Total Weight of Segments				5984.02 lbs.

chosen thicker stock than necessary but have, at the same time, increased the capacity of the press.

The center rib extending from the main shaft hub to the face of the frame is the full width of the frame and is in direct compression as are both side frame members and all vertical inner ribs. These vertical ribs are so cut that the compressive load is on the ribs themselves and not on the welds. The welds, therefore, need serve only the purpose of holding the ribs in position, as shown in Fig. 3.

The commercial welders are of the opinion that a frame of this type should be heat treated to relieve any stresses that may be set up in welding. I believe that these stresses could be sufficiently relieved by peening after each weld and point out that no attempt has ever been made to stress relieve our frame castings, and it is quite apparent that there are cooling stresses because it is not uncommon to find one that is cracked. I also believe that the constant shock loading will tend to reduce the stresses without distorting the cutting area because of the boxlike construction.

A thorough study has been made of the procedure and cost of making this particular frame and Fig. 5 shows the way the frame has

been broken up for analysis. Every part has been given a letter which corresponds to the letters on Fig. 6 which is a 1/16″ size layout of the most economical way to cut one frame from the stock shown. These layouts are calculated to leave the waste in large segments which need not be waste entirely because parts for other frames could be cut from them. In addition, the frame segments are laid out to make one cut serve for the edges of two segments wherever possible to further reduce the cutting costs.

The flame cutting costs are a combination of figures based on recent quotations and I have taken as an average, the following:

Labor	$ .75 per hour
Overhead while using equipment	$ .75 per hour
Oxygen	$1.40 per 100 cu. ft.
Acetylene	$2.80 per 100 cu. ft.

Stock	Rate of cutting inches per min.	Cu. ft. of Acetylene per min.	Cu. ft. of Oxygen per min.	Cost per inch
1/2″	18	.2	1.5	$ .0028
3/4″	15	.23	2.0	.004
1″	14	.23	2.3	.0045
1 1/4″	13	.25	2.8	.0054
1 1/2″	12	.27	3.3	.0065

The amount of cutting and the costs for the various thicknesses of stock is as follows:

Stock	Number of Inches	Cost per Inch	Total Cost
1/2″	105	$ .0028	$ .29
3/4″	283	.004	1.13
1″	968	.0045	4.36
1 1/4″	36	.0054	.19
1 1/2″	75	.0065	.44

Total Cost of Cutting $6.41

The arc welding costs, as taken from "Procedure Handbook of Arc Welding Design and Practice," are computed for fillet welds which are practically the only type of welds used on this frame, and incidentally are much faster and less expensive although welded both sides of the abutting plates.

Labor	$ .75 per hr.
Overhead while using equipment	$ .75 per hr.

Current and electrode cost is taken as recommended and is for single fillet weld only.

Stock	Beads	Amps.	Volts	Speed inches per min.	Lbs. of Electrode per inch	Cost per inch
1/2″	3	190	30	120	.058	$ .0199
3/4″	6	190	30	48	.152	$ .0501
1″	10	190	30	27	.27	$ .0890

Where 1/2″ plate is abutting any other plate 3 beads are used. Where 3/4″ plate is abutting any other plate 6 beads are used. Where 1″ plate

is abutting any other plate 10 beads are used and these costs are computed on this basis only.

The amount of welding of the various segments is as follows:

Stock	Weld No. of Inches	Cost per Inch	Total Cost
½" welds	318	$ .0199	$ 6.32
¾" welds	485	$ .0501	$ 24.30
1" welds	1540	$ .089	$137.06

Total Welding Cost $167.68

The number of inches of both cutting and welding is taken from the original layout which is too large to include in this paper and these figures include the amount of cutting needed to bevel the edges that require a corner butt weld.

The steel costs are based on a quotation submitted in January 1938.

Stock Thickness	Cost per 100 lbs.
½"	$4.07
¾"	$4.07
1"	$4.07
1¼"	$4.07
1½"	$4.32
2"	$4.32

Using these figures for the basis of our stock cost and having computed our stock sizes and segment weights the data is as shown:

Stock	Size of Stock	Stock Weight	Segment Weight	Waste	Segment Cost	Waste Cost
½"	24" x 42"	138 lbs.	113 lbs.	25 lbs.	$ 4.59	$ 1.01
¾"	42" x 54½"	480 lbs.	425 lbs.	55 lbs.	$ 17.29	$ 2.23
1"	60" x 120"	2016 lbs.	1636 lbs.	380 lbs.		
	44" x 30"	369 lbs.	268 lbs.	101 lbs.	$ 77.49	$19.57
1¼"	9" x 21"	66 lbs.	66 lbs.	00	$ 2.68	
1½"	42" x 24"	405 lbs.	354 lbs.	51 lbs.	$ 14.12	$ 2.36
2"	Billets cut to size					
	44¾" x 59½"	1484 lbs.	1484 lbs.	00	$ 60.40	
	12¾" x 42"	300 lbs.	300 lbs.	00	$ 12.21	
Main Shaft Hub		1610 lbs.	1338 lbs.	272 lbs.	$107.04	$21.76

From these figures will be found a waste cost of $46.93 of which we will absorb a loss of 25% and since the only expenses involved are stock, cutting, welding and labor the following are the total welded frame costs.

Actual stock cost of segments	$292.82
25% of cost of waste	11.73
Cost of cutting	6.41
Cost of welding	167.68
Cost of rough turning hub—(estimate)	12.00
Fatigue—10% of total time at $ .75 per hour	5.47
Helper during entire period at $. 60 per hour	48.15
Total Cost of Frame	**$544.26**

Total Weight of Frame—Stock		5984 lbs.
—Electrode		497 lbs.
		6481 lbs.
Total Time to Make Frame		$80\frac{1}{4}$ hrs.

The data on the cast iron frame is as follows:

Weight—(average)	9253 lbs.
Cost @ $6.60 per 100 lbs.	$610.70
Cost of pattern per frame to date	243.00
Total Cost per Frame to Date	**$853.70**

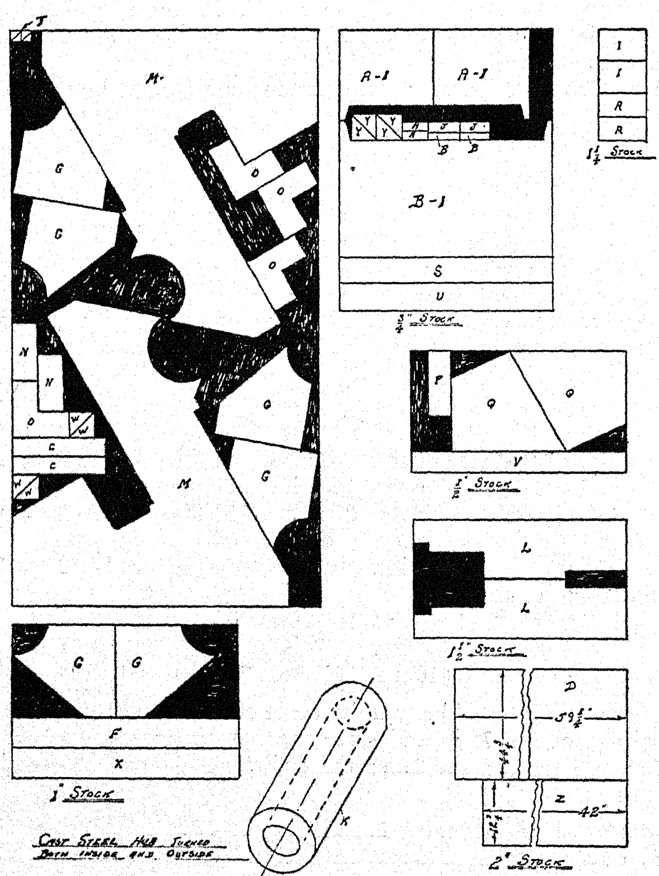


Fig. 6. Layout of most economical way to cut frame.

It may seem unfair to take the pattern cost per frame to date, since we still have the pattern and the unit cost will be reduced when and if we use it, however, there is no guarantee that we will use it and the cost has been pro-rated as I mentioned previously.

Without including pattern cost, our cast iron frame is at present more expensive than would be the welded steel frame and the figures that I have given have not been favored in the least, therefore, any cost difference in those shown should be to our advantage.

Not only have I used heavier stock than was necessary but have also added a high percentage of overhead which may not exist.

These figures, naturally, are dependent upon using modern equipment but this equipment may be purchased at a cost no greater than is now paid for a set of patterns and could be used for various other purposes.

The savings do not end with the completion of the welding because with a fabricated frame the finished surfaces can be held very close to dimensions and 1/8″ of finish is not unusual, whereas, with our present cast frames we normally allow 3/8″ to 1/2″ of finish on all surfaces and where the frames are tapered for draft we frequently have 1″ or more finish in the center. Naturally this means more planing time and a good deal of waste material.

A further saving would be realized in painting the welded frame because there would be no snagging necessary and, the rolled steel

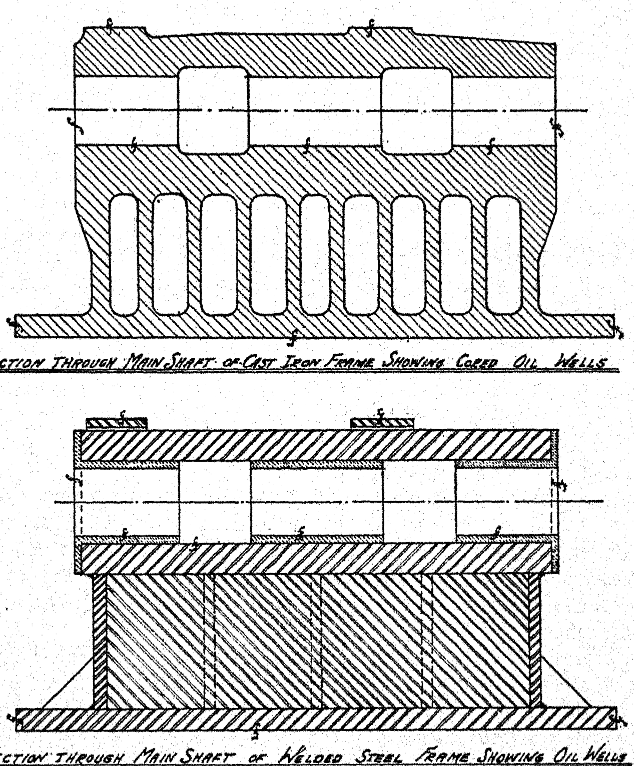


Fig. 7. Sections of cast iron and welded steel frames.

plates being smooth, there would be no necessity to use several coats of filler paint as is now being done on the castings.

Fig. 7 shows the section view of both the cast iron and the welded frames and attention is called to the oil reservoirs for the main shaft. These reservoirs are necessary for proper lubrication and we find a particular advantage in the steel frame.

Obviously we cannot run a steel shaft in the cast steel housing without using a good bearing metal and therefore would press bronze bushings into the housing as shown. By spacing these bushings we will have the oil reservoirs and can be certain that they are perfectly clean.

The cast iron frames have the cored reservoirs and since they are not bored out we cannot be sure that all core sand has been removed and a few costly rebore jobs have been attributed to this cause alone.

The only wearing parts of this frame are the main shaft bushings and at such time as the press should come back for rebuilding we could replace these bushings and have a frame absolutely as good as new.

The difference in weight is important because not only would the frame be easier for us to handle, and the shipping cost be lessened, but also this difference of almost 1½ tons might mean that where a machine has to be installed in an upper floor and carried up in an elevator it would be possible to ship the press as a unit rather than in sections which necessitates sending men along for an assembly job.

The original intention of this paper was to show how a new press could be made more economically by welded construction than to make new patterns and have one made of cast iron.

To illustrate this point a standard machine for which we have patterns was used and the foregoing figures have shown quite definitely, in spite of a very high overhead factor that even our standard machines can be made much stronger, lighter and at much less expense.

A substantial saving will result in the planing time and the smoother surface would speed up and give a much better paint job.

In addition a saving to the purchaser would result from the lighter shipping weight and perhaps also from a less costly installation.

Add to these advantages the fact that we would keep more men employed in our own factory and also any changes that were desired would not involve an expensive pattern change and it is obvious that one can speed up production and at the same time save a considerable amount of money by welding these frames.

Of the many platen press manufacturers in this country and abroad this writer does not know of any who does not cast the frames.

Platen presses are put to much heavier service than is most machinery and if cast iron has been strong enough in the past surely a welded steel frame will be a great deal stronger and the cost per pound is only about ⅔ as much.

Perhaps this study will result in the adoption of welded construction for press frames in the future and if so there is no reason why we should not be able to quote on a machine of any size at a price and with a delivery date within reason.

Chapter XXVII—An Arc Welded Manipulator

By J. O. BISHOP,
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For what does it profit a man if he has the most efficient welding sets conceived by modern engineers, the finest welding electrodes that metallurgists produce, the best small accessories such as electrode holders, helmets and hand tools, in fact has all of the appurtenances for tomorrow's welding and engages the most skillful of mechanics in an effort to accomplish a superior grade of workmanship if he has to depend upon the methods of yesterday to handle the work thus nullifying the advantages of all favorable factors by allowing his men to pry and lift or await a busy crane or to wallow on the floor or hang by their fingers, to do unnecessary acrobatics in overhead and vertical welding when a simpler, safer and economically more satisfactory method is available. By any method of figuring it is manifest that good positioning devices will do more to improve welding both as to quantity and quality than any other one mechanism since the development of welding generators.

To illustrate these points this paper is submitted.

For purposes of brevity throughout this article all fabricated parts joined into rigid, homogeneous units by welding may be referred to as "weldex" and a plant in which welding is done may be referred to as a "weldery". It might also be pertinent to explain here that the mechanism herein described was built and is used in a large plant devoted to the manufacture of oil well drilling and production machinery.

Characteristic of its accomplishments, the machine herein described is called a manipulator, and manipulate it does through 360 degrees in either the vertical plane or horizontal plane thereby presenting the work thereon at any conceivable position with a minimum of effort to workmen or motors.

Its unique design, its absence of any extensive "blind" areas, permits access to almost any part of the piece being worked upon, either top, bottom or sides, without subsequent resetting after once being affixed into position.

The more important units which comprise this mechanism are; a foundation including surfaces on which the weight of the machine and its load are mounted with a suitable clearance around and under the machine to permit of its intended full use, pedestals on which the power driven assembly is carried, a cradle with its driving motor and gears to provide rotation in another set of directions, a suitable floor or platform, easily portable, to facilitate the approach to or retreat from the points of operations, a car with readily adjustable ladders to increase the efficiency of approach to and retreat from the work locations and adequate motor control apparatus. The following reference to the several photographs and drawings will assist in illustrating these inherent features and such accessories as found to be advisable.

Also worthy of note is the fact that the consideration of the use of castings, in the construction of this machine, was given but little attention because preliminary estimates and past experience have taught that in a case such as this, wherein patterns and core boxes would be used but once or twice, the weldex may be manufactured for the price of patterns thereby saving the cost of castings.

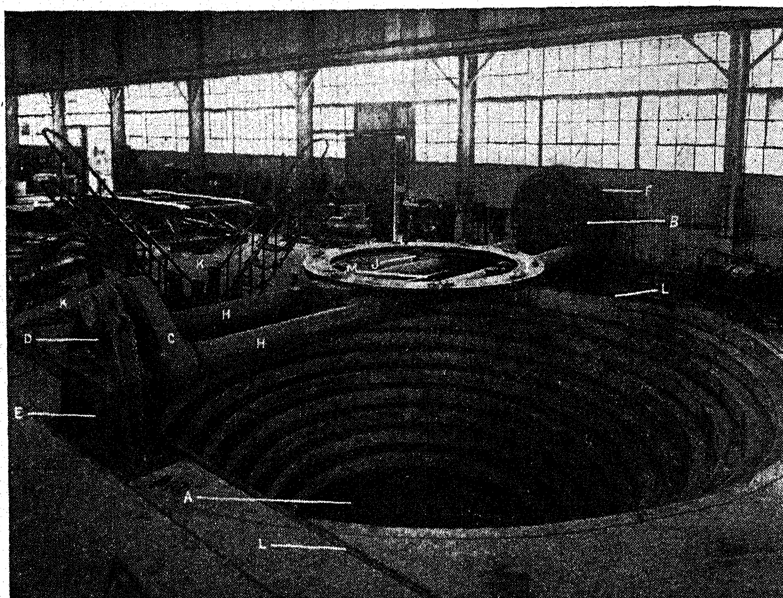

Fig. 1. The arc welded manipulator mounted over pit.

Reference to Photographs.—Referring to the photograph, Fig. 1, which shows a general view of the manipulator in idle position, symbol "A" indicates the pit necessary to clear work of 30 feet in length. The work is usually held in the middle and may be rotated end over end in either of an infinite number of planes.

At "B" on photograph, Fig. 1, is a combination cradle plate and cradle rotating gear mounting while at "C" are views of the companion cradle plate. At "D" is shown a spherical roller bearing housing which in turn is mounted on a sub-base marked "E".

Symbol "H" shows the tubular cradle frame members upon which is mounted a turn-table ring indicated at "I" by means of four retaining rollers marked "J". On the top of the turn-table will be noted a number of the toe clamps with cap screws which are employed to secure the work upon the table. Symbol "K" on photographs, Figs. 1 and 2, shows a movable half-octagonal shaped working platform mounted on three wheels, which roll on rails "L". Symbol "M", Fig. 1, shows part of the turn-table driveshaft which appears at a better advantage on photograph, Fig. 3. This it will be noted, is driven by a gear motor mounted on one tubular member and drives through companion sets of worms and gears to a pair of spur pinions which finally drive the turn-table gear.

Visible in each of the four photographs, Figs. 1, 2, 3 and 4 is one of the more unique features of this project. Referring to photograph, Fig. 4 a car marked "O" travels on a pair of rails "N". Upon this car a swivel plate "P" supports two adjustable ladders "Q" which may be lowered or raised to an angle of 60 degrees either above or below a level position.

On the column are two push button control switches for the operation of the motors involved. These switches are arranged and wired so that the driving mechanism functions, in the case of either motor, only when the operator holds the button in contact position. Release of pressure stops the motor on the line involved.

Fig. 2. "K" is half-octagonal-shaped working platform.

Details of Construction.—By way of reiteration and more specific description of detail let us first describe the construction of the foundation. After the necessary excavation was finished and the slopes of the pit carefully trimmed so as to minimize the waste of concrete, the bottom of the pit was leveled and a slab of concrete floor was laid after which an approximately round wooden ring was constructed on the floor in the bottom of the pit. Around the perimeter of the pit at the upper floor level, another approximately round, that is, polygonal timber ring was laid down. From the lower ring radially and upwardly 2" x 12" timbers were set edgewise at approximately 15 degrees apart and connected to the upper ring. These 2" x 12" timbers first having been prepared by attaching short 2" x 6" uprights by their upper ends at intervals representing the steps in the concrete. This being finished, pieces of ¼" plywood were cut to the width of the rise of the step and slipped behind

the 2″ x 12″ timbers and nailed to the upright. The minimum thickness of the concrete at the inner corner of the steps was permitted to be about four inches. After the forms were prepared conduit was run for four convenience outlets for welding leads and similar outlets for electric light extensions. Two indentations were prepared in the forms to receive the machine pedestals. After this preparation the concrete was poured. In stripping the forms it was found that the ply-wood had distorted somewhat due to pressure but the result was sufficiently accurate for all practical purposes.

In general, it will be stated that the manipulator was designed to carry, (with proper factor of safety), a load of ten tons. The turn-table face being about one foot below the cradle center it is estimated that an average job 5 feet in height being placed on the table will approximately balance the machine while in operation. Necessarily, flat work of less than two feet in height will cause the setup to be slightly overbalanced on the same side as idle operation while a job of more than five feet in height will probably overbalance on the opposite side. Depending upon the shape somewhat, jobs of up to 30 feet in length may be rotated 360 degrees in any plane.

In the bearing pedestal there is a difference in the two necessary pieces in that one requires a journal box for the shaft of the cradle rotating pinion and the other, the companion pedestal, being plain in this respect. The tubes are constructed of 13⅜ O.D. 49.44 pound seamless casing, range C in length, or, in other words, lengths which are furnished in approximation of 30 feet. The particular pieces of casing available in this instance being somewhat short of the average length and in order to reinforce the junction point in addition to affording extra length the regular collars or pipe couplings were employed. Attached to these are the steel flanges for connection to the cradle plates. Obviously these tubes could have been welded to the cradle plates with economy but bolted and dowelled joints were decided upon with a view to future moving of equipment. At four locations on the inner flanks of the tubes are pads provided for the connection of the combination cross-member gear cases while on the outer flanks of the tubes are four pads to which are bolted the spindle brackets for the turn-table bearings. These spindle brackets and the turn-table bearing rollers provide for both radial loads and thrust loads in either direction.

The Turn-Table.—The turn-table itself is unique in several respects. In the first place it was difficult to secure plates of sufficient dimensions to make the two necessary rings of 146 inches and 147 inches in diameter, therefore, these were produced by attaching, by means of welding, six sectors in each case. The problem of producing relatively true and flat rings was solved by carefully laying out the sectors and cutting same on a shape-cutting machine, after which the ends of each sector were chamfered on both sides of the plate. Following this, two plates were attached by means of tack welds after which they were welded together, being frequently turned over so that shrinkage and subsequent warpage might be controlled. To one of these two sectors a third was attached in a similar manner. This three sector half was then laid aside and the

other half of a ring was likewise constructed. The four welded joints on the halfs were then rough-ground by hand grinders so that they could be straightened by heating while lying on a surface plate. Satisfied with the correctness at this point the two halves were then brought together and welded in the manner heretofore described. These final joints were then rough ground by hand. After both rings were prepared they were then stress relieved following which they were clamped together and a

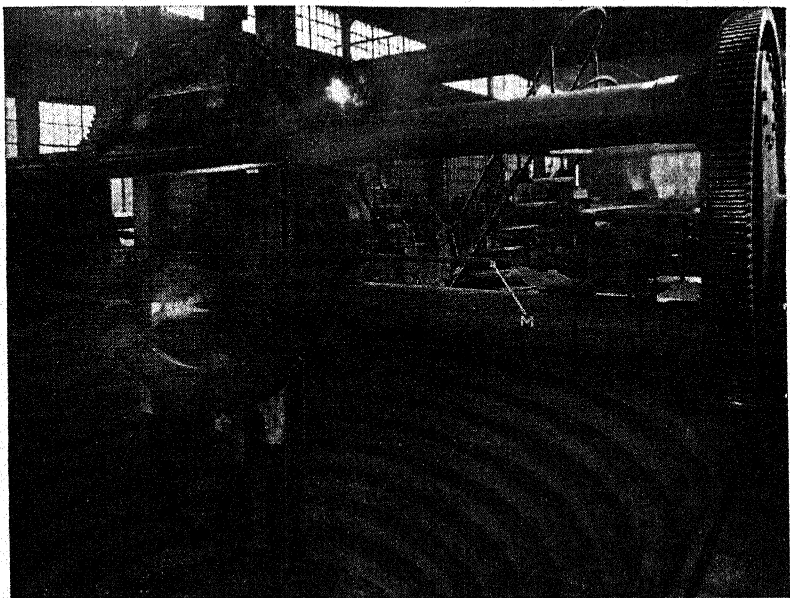

Fig. 3. Close-up of manipulator showing drive.

series of holes were drilled through them into which shouldered spacers were inserted. These spacers had their smaller diameters turned to a length approximately three-quarters of an inch shorter than the thickness of the plates and the welding of the spacers into position was applied into the holes at the end of the spacers.

At the outer periphery of the lower plates the turn-table rotating gear is cut. There being no gear cutter available that would even approach a gear of more than 12 feet in diameter, such as this is, it became expedient to flame cut the gear. This job was performed by a shape cutting machine and other incidental mechanisms somewhat. An oil well rotary machine was available and convenient to use in readily supporting and spacing the work. The gear was super-imposed and trued concentrically upon two structural members laid across this rotary machine table. Teeth were spaced by drawing radial lines on the side of the gear at proper intervals and a template of the proper form of gear tooth gash was made and this single tooth template was used repeatedly.

Indexing the gear was accomplished by means of aligning the radial lines with a straight edged indicator attached to a building column in close proximity to the job. In the cutting of these teeth several spaces were skipped between the first, second and subsequent gashes so as to move beyond the area heated by radiation while cutting the preceding teeth, thus contributing to greater accuracy by avoiding undue distortion. This procedure proved to be gratifying as but little hand finishing was required on the teeth.

Later, the turning having been finished on the upper plate of the turn-table, it was then laid out, drilled and tapped for some 120 holes intended to be used for the work holding clamps.

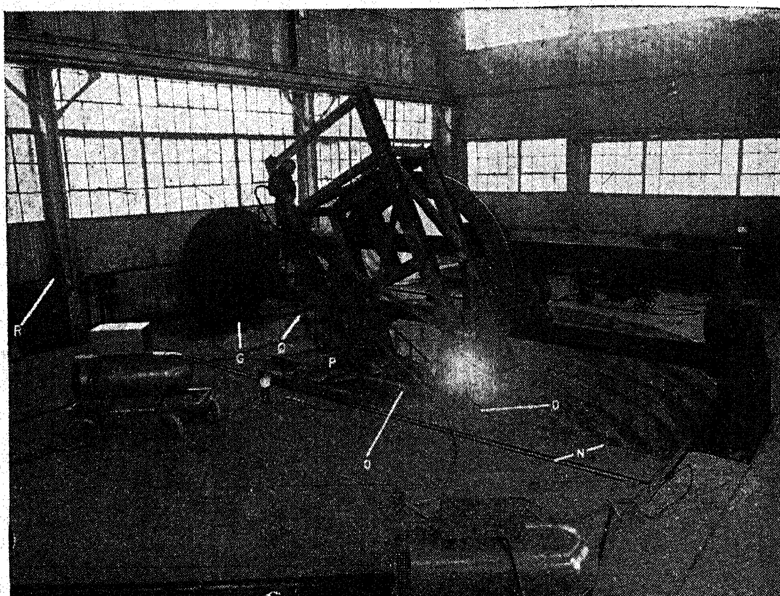

Fig. 4. Details of manipulator: "O" car; "N" rails; "P" supports for adjustable ladders; "Q" ladders.

Other Pertinent Details.—Since the turn-table gear was necessarily of a rather narrow width for its diameter, it is driven by two pinions, opposite each other, and thus not only distributing wear and achieving better balance but contributing to the utmost safety in operation. By noting photograph, Fig. 3, the method of driving the worm gears will be seen. At detail marked "M" a reversible gear motor of 5-horsepower, 6-pole, 4.50 to 1 ratio, 220 r.p.m. output speed, with brake, drives a worm shaft through flexible couplings from one end of the tube. Some slight accessibility to the work may have been sacrificed in that this drive shaft could have passed through the tube and thence to the worms. However, it is considered that such procedure would not only have complicated matters by way of unnecessary bevel gearing and extra bearings but would have unavoidably weakened the cradle tube.

Fig. 5 shows the cradle drive reduction gear and motor. This 5-horsepower 4-pole motor is geared to 127 r.p.m. or a ratio of 11.9 to 1 before reaching worm gearing of 40 to 1 thence to a 17 tooth pinion which turns the 162 tooth cradle gear. The worms and worm gears, bearings and oil seals and gear motors are regular commercial items.

Besides providing a method of ready accessibility to the work and at the same time permitting quick removability before rolling the manipulator, the rolling floor is so constructed that it has a track along the forward edge which lends itself very handily to the use of not only carrying the adjustable ladder car but may conceivably be used for automatic welding or flame cutting equipment, either stationary while the manipulator turns, or being traversed in a straight line while the manipulator is at rest. Note that the rails are built into the structure of the parallel trusses. This framing is covered with 2" x 12" planks which in turn were treated with an asphalt-asbestos compound to minimize flamability. The rolling floor and ladder car are manually actuated.

Fig. 5. Cradle drive reduction gear and motor.

In operation, the machine is brought to a level position as shown in Fig. 1. The hold-down clamps and screws have been removed. The work, having first been cut, fit and tacked on a surface plate, is lifted upon the turn-table by means of an overhead crane. By judicious management, it can usually be located so that no welding zones on the under side are obstructed by the turn-table ring or cradle tubes. The job is

then bolted securely in place by clamps and capscrews and the operators check it over to ascertain that tacks are heavy enough to permit the work to be rotated with safety. Usually there are a number of horizontal, or "down-hand," welds to be made at this time after which the work is then rotated in either or both planes to bring the welding zones into position so that the joints form a natural angular groove or vee to permit the welding to be accomplished in a flat or "down-hand" position. This is the most important feature of any positioning machine.

It is obvious that this procedure permits of as high temperatures as are considered good practice and at the same time permits the operator to use the largest practical electrode. This may be looked upon as the ideal method of welding not only because of the resultant economy in heat and electrode dimension but the ease by which equal and complete fusion may be produced on both of the angles. Several welds in one position may be completed, the operators may then step away, remove the rolling floor and rotate the work to a new position and proceed as before. The convenience of this procedure contributes materially to frequent turns and welding at various locations, therefore, lessening the concentration of stresses with resultant distortion.

Fig. 4 shows an oil well draw-works and driving unit sub-base being operated upon. Jobs of this nature, six or eight feet high, nearly 30 feet long and weighing several tons, are easily handled. On Fig. 3, the underside of an oil well draw-works frame is discernible while on Fig. 2 the operation on the bearing supports of the same frame is seen.

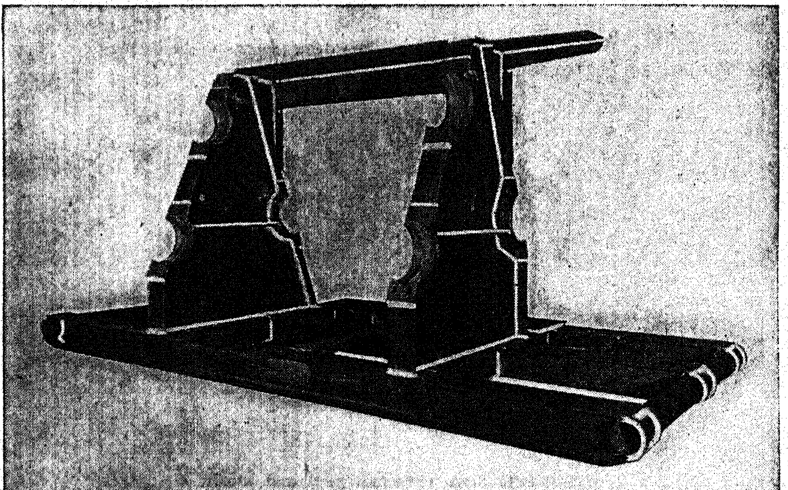

Fig. 6. Draw-works main frame assembly.

A number of large tanks have been constructed on this manipulator. All welding, as is the case with bases and frames, have been completed with but one handling by crane. Vertical or overhead welding was not necessary. In a case of this kind seats are provided so that the welder may be supported with comfort along the angles being worked upon.

Cost.—Realizing that there are a number of variable factors entering into cost accounting in different plants it would necessarily follow that any cost figures given herein would be peculiar to the plant in which the work was executed. With this in mind a typical summary is offered from which deductions may be drawn for any particular plant. Administrative overhead is not calculated within these tabulations.

LABOR COST

Item	Hours	Price per Unit	Remarks	Cost
Foundation:				
Excavations, common labor removing debris with aid of overhead crane and skip	192.00	$0.50		$ 96.00
Crane operator	12.00	.68		8.16
Preliminary concrete labor:				
Bottom slab	9.00	.70	Average—six men	6.30
Carpenter work on forms	276.50	.70	Average—three men	193.55
Sawing off six pieces for rails	1.00	2.50	Including machine overhead	2.50
Welding short cross pieces under rails to improve stability	7.50	.96		7.20
Setting rails	4.50	.75	Average—three men	3.38
Electrical labor installing conduit, etc.	24.00	.80	Average—mechanic and helper	19.20
Common labor mixing and pouring concrete	81.00	.70	Average—nine men	56.70
Cement finishing	32.00	.82	Average—mechanic and helper	26.24
Common labor stripping forms	28.00	.50		14.00
Construction of Machine:				
Acetylene cutting	53.50	3.80	Average—including gases	203.30
Sawing—metal band saw	3.70	2.40	Including machine overhead	9.15
Welding—metallic arc	541.50	1.40	" " "	758.10
Lathe work	217.00	2.80	" " "	607.10
Milling machine work	54.80	2.75	" " "	149.70
Layout work	20.60	.96		19.78
Drill press work	40.20	2.75	Including machine overhead	110.55
Planer work	12.25	2.90	" " "	35.53
Sand blasting	7.00	3.00	" " "	21.00
Key seater work	3.80	2.60		9.88
Shaper work	15.20	2.75		41.80
Heat treating	18.75	3.10	Including departmental overhead	58.13
Floor work — assembling, two machinists and two helpers	496.15	.79	Average—two mechanics and helpers	391.95
Painting	17.00	.80		13.60
TOTAL				$2429.57

Additional to the foregoing labor the following material lists are submitted. Attention is called to the fact that in several cases advantage was taken of salvaged materials to minimize the cost.

MATERIAL COST

Item	Quantity	Price per Unit	Cost
Foundation:			
Lumber	1300 board feet	\$36.00 per M	\$ 46.80
Plywood—¼" x 24" x 10'	60 pieces		49.44
Cement	182 sacks	\$0.55	100.10
Crushed rock	32 tons	2.00	64.00
Sand	22 tons	1.50	33.00
Bolts, nuts and washers			3.06
Pipe—scrap—2½"—60 lbs.			.60
Conduit—1¼"	90 feet	.18½	16.65
Conduit boxes	5	.50	2.50
Rails—40-lb.	43 yds., 1720 lbs.		21.50
Cross pieces—scrap	450 lbs.		2.25
Nails—common—15 lbs.			.42
Machine Construction:			
Ball bearings—new	19		225.59
Ball bearings—salvaged	5		15.92
Oil seals	8		8.65
Purchase of gear cutting	2		47.00
Chain couplings	5		49.89
Magnetic reverse switches	2		65.10
Push button switches	2		
Worm gears with worms	3 pair		148.84
Gear motors	2		366.56
Screws—assorted			18.86
Nuts—assorted			4.10
Machine bolts—assorted			7.09
Cotter pins—assorted			.06
Stud bolts—assorted			2.80
Shims—assorted			.40
Pipe plugs—4" x ¼"			.08
Hydraulic pipe			2.87
Forgings	3827 lbs.		212.52
Cold rolled steel	166.30 lbs.		8.06
Hot rolled steel	22779.00 lbs.		580.74
Steel castings			83.44
Ground gage stock			.38
13⅝" O.D. 68-lb. seamless casing	60 feet		218.59
Extra couplings for above	2 pcs.		18.80
Spiral type roller bearings			40.81
Drill rod—1" round x 7"—1½ lbs.			.25
2" x 12" S1S2E Oregon pine No. 1 com.	1024 board feet	\$36.00 per M	36.86
Paint, asphalt, etc.			13.21
TOTAL			\$2177.37

FOUNDATION TOTAL	\$ 773.55
MACHINE CONSTRUCTION TOTAL	4606.94
COMPLETE TOTAL	5380.49

Justification.—Preceding the advent of this manipulator in the weldery where it is used it might be well to picture the method employed at that time to accomplish the class of work required.

Assuming that a relatively flat structure such as a machinery base was being constructed of structural beams, channels, angles and plates, usually the assembled and tacked frames were removed from the surface plates and set up on horses, by an overhead crane, for the welding of the flat joints on one side. This finished, the crane was again called, hooked on to the job and the work flopped over. The word "flopped" is used advisedly for such was the case, it being practically impossible to turn over a heavy piece with a single hook crane without at some point in the process allowing certain slack to occur and, when the work overbalances, it is bound to drop and jerk. On no few occasions this resulted in snapped chains and cables not to mention damaged work.

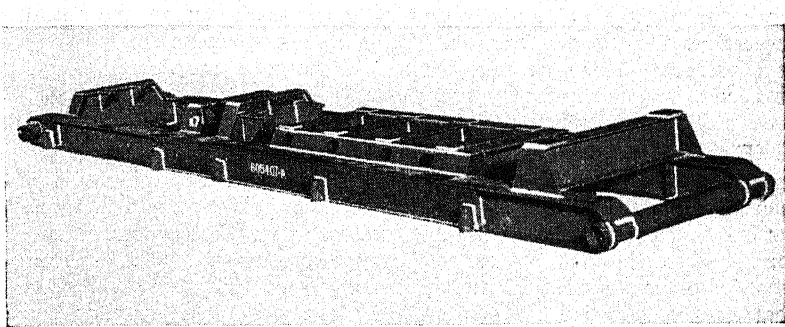

Fig. 7. Rig drive base.

After the welding on the reverse side of the base was accomplished the work was then set up on edge and lashed against columns set in the floor, the welders standing on scaffolding and welding all the seams within reach from that position. Following this, the crane was called again and the work was again flopped over so as to bring the opposite edges upward and work proceeded as before. A similar set of actions are necessary to work on the ends. Obviously, it is necessary to do certain vertical and horizontal welding during such procedure. It is also apparent to anyone acquainted with shop work that it is extremely dangerous to be near a job being handled by a crane in the manner described and as a safety practice it was always necessary for those working in the vicinity to cease operations and move to a safe distance. The whole procedure caused a great loss of time because of difficult approach to the point of operation, because of necessity in using inefficient electrode diameter and reduced heat, and because of the frequent use of the overhead crane, thus perhaps interrupting other important duties of said crane and, above all, causing all neighboring workmen to seek safety by retreating from the vicinity.

Prior to the acceptance of welding by the oil production industry the draw-works or hoisting mechanism usually consisted of babbitted cast iron journal boxes bolted to hardwood uprights which were in turn bolted into the derrick near the floor. In these boxes were shafts on which were mounted the draw-works cable drum with its brake rims and the

various sprockets and clutches that were used. The draw-works mechanism of today has evolved a long way from that of fifteen years ago, it now being a completely unitized steel frame with integral steel boxes to carry self-aligning roller bearings which support larger and better quality shafts, drums, rims, machine-cut flame-hardened sprockets and clutches all of which are elaborately enclosed by guards while being assembled at the manufacturer's plant instead of being put together piecemeal at the well as formerly.

Another revolutionary practice is the substitution of an all welded steel sub-base for concrete foundations under the above mentioned draw-works and its steam, gas or electric driving unit. The gas and electrical drives themselves, being necessarily of higher inherent speeds, a little more difficult to throttle and reverse than the steam engine, the output speed controlled by belt, chain or gear mechanisms, are an entity known as a rig drive. This style of a driving unit has a separate base which is also completely fabricated by welding structural beams, channels, angles, tubes and plates into one homogeneous piece.

The foregoing explanation will assist the reader in understanding, especially if he is familiar with oil field practices and the rapid development of the industry, that almost every job is custom-built and therefore not exactly comparable to another job designed for a like purpose. Therefore, it goes without saying that comparative costs are difficult to ascertain from cost accounting records. However, to the initiated, who have observed the general utility of the manipulator, there is no question that its cost is overwhelmingly justified.

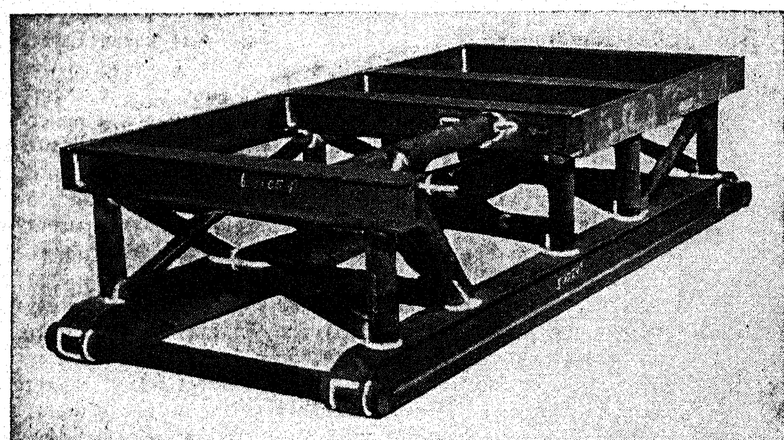

Fig. 8. Sub-base.

In substantiation of this fact three typical jobs, those mentioned above, will be illustrated. Fig. 6 shows that part known as a "draw-works main frame assembly." Its overall dimensions are, length 18 feet, width 92¾ inches, height 92 inches. Fig. 7 is a base designated, "rig drive base."

Overall it measures; length 28 feet, width 70 inches and height 25¼ inches. Fig. 8 is a sub-base of which the overall dimensions are, length 17 feet 8½ inches, width 8 feet and height 48 inches. To accentuate the welds in these three examples the welded areas were touched up with white paint. The accompanying chart illustrates the comparative results. Cutting, fitting and assembling time is omitted to avoid confusion.

Name and Number of Work Piece	Total Length of Welds Lineal Ft. of ⅜" Bead or Equivalent. (.070 sq.in.)	Welding Time on Manipulator Hours	Comparative Piece Not Welded on Manipulator. Reason for This Practice	Total Length of Welds Lineal Ft. of ⅜" Bead or Equivalent. (.070 sq.in.)	Welding Time Hours
Draw-works Main Frame (Fig. 6)	821.30	109.40	Draw-works Main Frame. This frame similar but smaller. Manufactured before manipulator was constructed.	692.70	143.70
Rig Drive Base Frame (Fig. 7)	575.00	77.90	Rig Drive Base Frame. Slight difference in overall length. Welded on horses and against columns because of more work scheduled than manipulator could handle.	575.00	113.40
Sub-Base Frame (Fig. 8)	402.70	56.00	Sub-Base Frame. Similar except beams, angles, and plates used for legs and braces. Manufactured before manipulator was constructed.	496.50	98.10

Throughout the foregoing tabulation the factor of a ⅜" fillet weld was used. This is equal to about .070 square inch area of cross section. By the same rule, a ½" fillet weld equals .125 square inch or 1.8 times a ⅜" fillet; a ¾ inch fillet equals .281 square inch or 4 times a ⅜" fillet. Examination of the tabulated figures indicates that the average speed in lineal feet per hour for a ⅜" fillet on the manipulator was; on the draw-works frame about 7.50, on a rig drive base 7.38 while on the sub-base was 7.19. Crudely positioned without a manipulator, similar pieces average about as follows; draw-works frame 4.82 lineal feet per hour, rig drive base 5.07 lineal feet per hour and in the case of a sub-base 5.06 lineal feet per hour. Viewing these figures as to percentage of time saved we find that, by taking time without the manipulator as a basis, the

average speed per hour on the three examples was nearly 7.36 manipulated and about 4.98 not manipulated therefore manipulating produces almost 48% of time saved. Experience has demonstrated that parallel savings are to be anticipated on all and sundry jobs, some greater and some lesser, which pass over this machine.

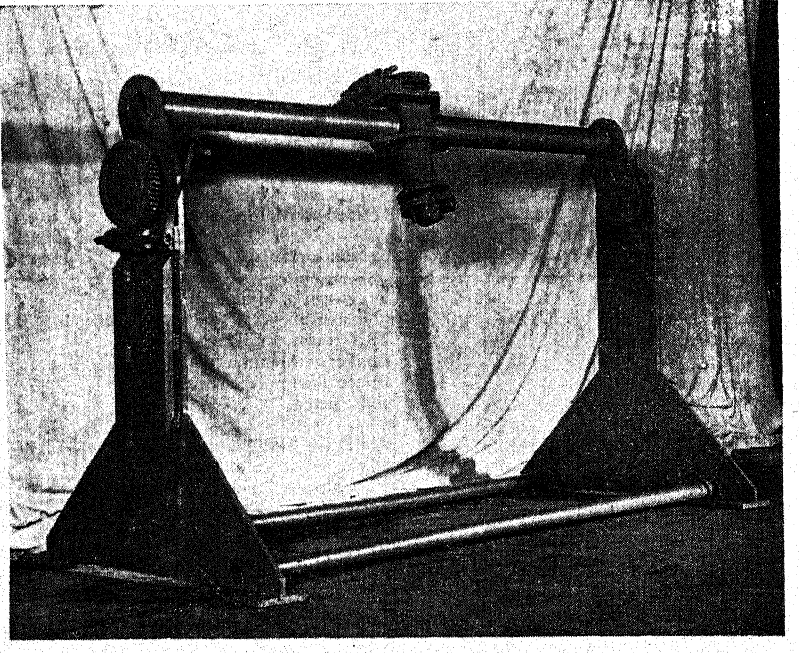

Fig. 9. Small hand-powered manipulator.

A representative month's work, in the weldery where this is written, will call for, on an average of six draw-works frames from which are saved; conservatively, 300 hours; ten rig drives or equivalent bases the savings on which are not less than 300 hours more, perhaps only one sub-base where at least 20 hours are saved and possibly thirty other miscellaneous bases and frames such as are used on small draw-works, pumps, seismographic petroleum exploring outfits and like structures wherein 270 hours total savings are again realized. Monthly total of savings would be 890 hours and if calculations were to be made on a premise of four dollars per hour for labor, shop and administrative overhead and material, (this latter is, of course, constant but nil), the value of $3560.00 would be extended. Yearly savings, demand permitting, would be $42,720.00 most of which is passed along to the trade. This on an investment of less than $6000.00. No weldery can afford to be without a manipulator!

In order that the reader may reconcile the figures with the available hours in one month it is pertinent to point out that the manipulator is

sometimes kept in constant operation, that is, 24 hours per day, 30 days per month, with always two, sometimes three and at times four men operating upon it. In addition, let it be understood that a small hand-powered manipulator, Fig. 9, is used as an auxiliary on pieces under 6 feet mean diameter such as the bearing supports or pedestals used on the draw-works which are previously fabricated before being assembled on the base. Results in savings effected by this small manipulator are approximately parallel to those of the larger machine.

To divert, momentarily, the reader's attention is directed to Fig. 10. Shown here is a manipulator designed and used for the sole purpose of assembling oil well rotary machines. The facility with which this operation is now performed vindicates the expenditure for this construction and tends to forecast the building of others for various purposes.

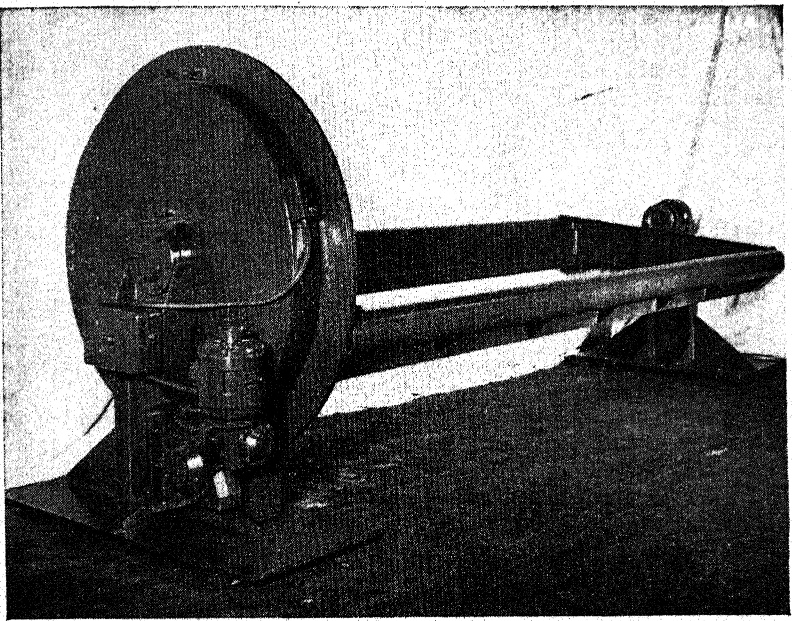

Fig. 10. Motor driven manipulator.

A Simple Test.—More eloquent than pages of persuasive argument are the results of a little test which was conducted in the interests of this paper. Anyone doubting the advisability of properly positioning their welding should make similar experiments.

A number of pieces of $\frac{5}{8}'' \times 3'' \times 23''$ mild steel were prepared by mitering one edge of each piece so that in pairs they would form a 90-degree angle. A crude holding fixture or jig was prepared to hold a pair of pieces while welding. A good average welder was assigned to the tests and instructed to perform the following four welds: One horizontal lower corner weld, one horizontal upper corner or overhead weld, one vertical weld and one horizontal positioned or "down-hand"

weld. In each case the weld was to be as nearly ½″ in depth as was possible to judge in manual welding. Time and other conditions were recorded by an observer. Elapsed time from the striking of the first arc until the particular piece was completed was taken. Voltage and amperage were read from the meters on the welding set. Specimens were weighed before and after operations. Fig. 11 pictures the four resultant specimens.

After welding was completed, the four specimens were steel-grit blasted and photographed. Following this, samples were sawed from each piece and surface ground for the purpose of subjecting the same to etching tests.

See Figs. 12 and 13 for results. Fig. 12 shows the four pairs of specimens prepared, etched and photographed before any subsequent heat treatment was performed. "A" represents two sections of a horizontal lower corner weld; "B", sections of a horizontal upper corner or overhead weld; "C", sections of a vertical weld while "D" shows sections of a natural down-hand weld. "D" was accomplished in two passes as compared to four to seven passes on all others. Delving briefly into the metallurgical aspects resulting from these tests it will be noted that of the two passes on "D" the final pass has a rather coarse grain structure gradually blending into the first pass which is perfectly annealed, the penetration is considerable and even. The surface contour indicates one that will better absorb and distribute stresses. The adjacent parent metal does not appear to be unevenly affected. In the cases of specimens "A", "B" and "C" the final passes, being considerably lighter in section, consequently appear less coarse in grain size but, on account of the deficient annealing effect of lower heat, these coarsenesses of grain size are dispersed throughout the welds, likewise, the annealed areas are probably less in total and are more scattered than in "D". Penetration lines in the specimens "A", "B" and "C" are shallow and uneven and there are decidedly certain disturbed areas within the parent metal surrounding the welds.

These identical pieces were annealed at a temperature of 1800 degrees Fahr. after photograph, Fig. 12, was taken. They were repolished, re-etched and rephotographed, the result shown on photograph, Fig. 13. This improved the condition of the parent metal in all cases to about an equal degree, the condition of grain size more in "D", and possibly "C", than in the instances of "B" and "A". The following table shows the important results in time saved.

Test	Nature of Operation	Electrode	Wt. Applied	No. of Passes	Voltage	Amperes	Total Time
A	Horizontal Corner Weld	¼″ 3/16″	31 oz.	3 1	32	220	31 min., 35 sec.
B	Overhead Corner Weld	5/32″	27 oz.	7	28	150	50 min., 29 sec.
C	Vertical Corner Weld	5/32″	32 oz.	4	28	150	51 min., 27 sec.
D	Horizontal Down Hand Weld	¼″	30 oz.	2	38	330	13 min., 46 sec.

These elementary tests, with fair discounting of the facts that the welder knew he was competing against time, no stops were made except to change electrodes and the job was of relatively short duration, are directly comparable to the results which might be expected in welding with and without the benefits of proper positioning of the work.

Fig. 11. Specimens arc welded for time test.

Conclusion.—Submission is extended that aside from the vital prerequisites for successful welding; such as, efficient welding sets, the finest of electrodes, a means of lifting heavy objects and, of course, skillful mechanics; that some method of easily and economically handling the

object to be worked upon, to present its numerous points of operation in the most advantageous position in favorable sequence, is the most essential requisite of the modern weldery. As a time saver any piece of machinery which returns 100 percent on its cost investment within a few months must stand unchallenged. Savings are typified not only in

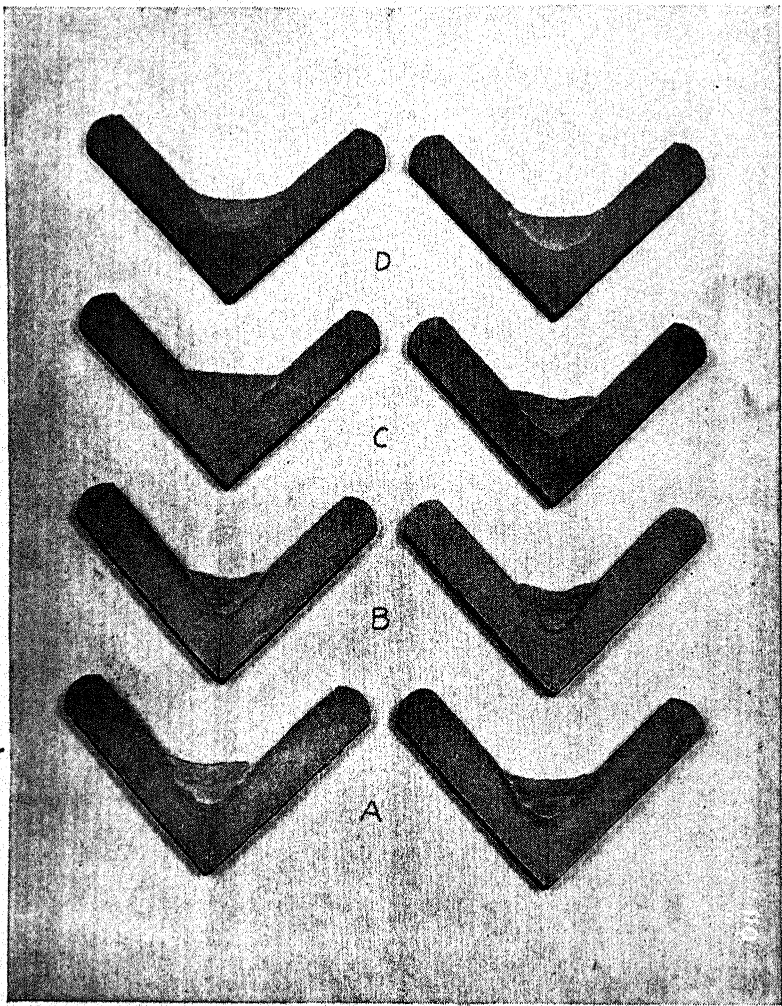

Fig. 12. Specimens prepared and etched before heat treatment.

faster welding due to increased heat and electrode diameter which might conceivably also be accomplished through positioning by simulated means in using crane and temporary supports but the greater saving in the possibility of proceeding with work once started without frequent long

waits for attention and rigging by an otherwise busy crane, by the non-apprehension of neighboring workmen for their safety while work on a manipulator is being moved, saving due to the availability of the crane for other work, savings accounted for in the obvious fact that there cannot but be less spatter loss, electrodes of the same diameter

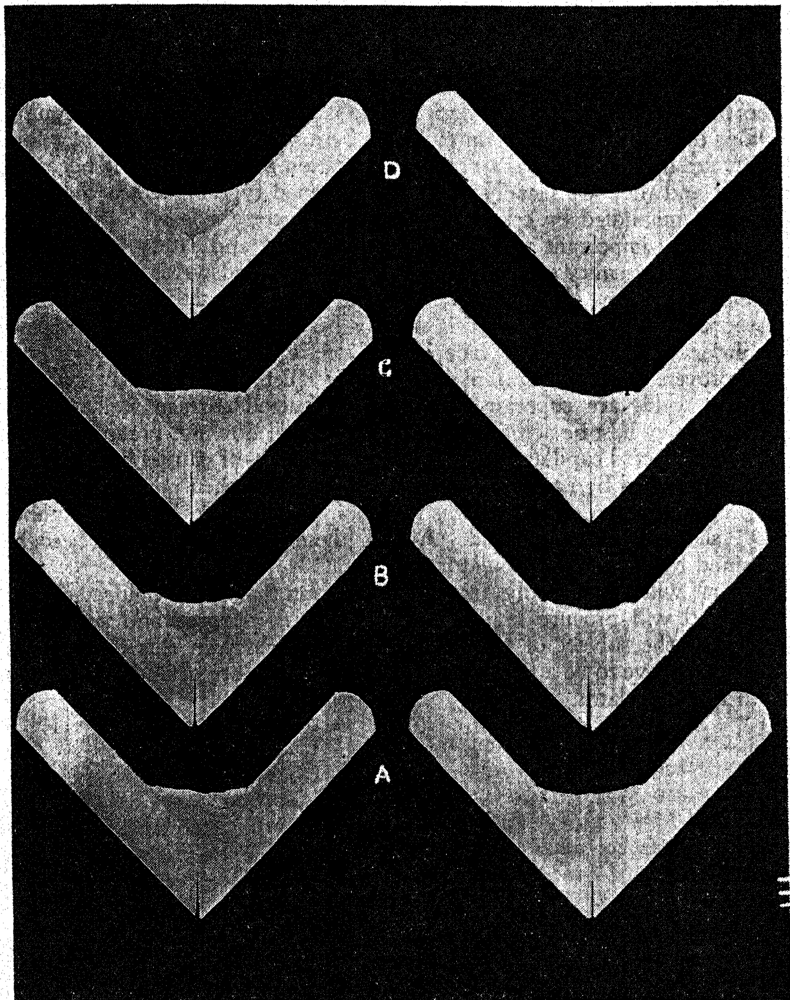

Fig. 13. Specimens repolished and re-etched.

and constituents considered, in a "down-hand" weld than in one in unnatural position. There is also saving in the fact that the predesigned and prearranged means of reaching the points of operation are readily accessible as opposed to the placing of ladders and scaffolds following

each movement to a new location for application of weld metal. Economy is, of course, the very essence of the thought behind the creation of a manipulator but fully as important is the factor of greater safety. It is granted that a workman might fall into the pit necessitated in this design but the expectancy is that he would fall more frequently if the work were propped up on the floor and approached by means of a carelessly placed ladder, or horses and boards than when provided with substantial and firmly attached approaches such as are indicated in the foregoing description.

Contention is made that the manipulator described in this paper is the best possible style yet designed to accomplish proper positioning. Other designs are deficient in either or both of the following particulars. They are limited to less than complete rotation in at least one if not more planes and they are usually of a solid platened type on which the work must be rehandled by crane to present the reverse side.

Equally important to the claims of economy and safety is the claim of improved quality of workmanship in general and welds in particular. Welders all know that whenever possible the appliance of metal with its subsequent radiation of heat is usually best applied at opposite points in order to distribute and balance the stresses. Engineering experience has proven that flat, and in the case of fillet welds slightly concave surface welds are superior to convex or bulged surface welds. Such welding may best be achieved through the freer flowing, greater shrinking, unrestricted capillary attraction of the fillet itself caused by increased heat as allowed by natural "down-hand" work as when performed while in proper position. Observe this result on photograph, Fig. 12. Symbol "D" shows positioned weld. All of these advantages may best be attained by using a manipulator.

Time will undoubtedly sustain the assertion that every weldery should have and will procure implements identical in purpose and similar in design to the subject of this discourse. Expediency in this direction is bound to prove to be a decision leading to the stability of and satisfaction with a manipulator.

Chapter XXVIII—Arc Welding and the 200-Inch Telescope Project

By Edmund G. Grant,
Associate mechanical engineer of the 200-inch telescope project of the California Institute of Technology, Pasadena, Calif.

This paper is dedicated to a modern proverb: "Efficiency as an engineer is the time spent in making an idea work compared with the time spent in trying to prove it will not work."

Preface.—A large sum of money was allocated, by the General Education Board of the Rockefeller Foundation, to the California Institute of Technology in Pasadena. The entire sum was to be used to build the best 200-inch telescope practical. Auxiliary equipment of an optical and mechanical nature, and all of the research so necessary to the success of a pioneering project, was to be provided. Science was to be given the most perfect telescope possible, with the most complete laboratory and other assisting equipment.

The 200-inch telescope, (See Fig. 1), will have four times the light gathering power and twice the focal length at the Cassegrain and Coude foci, of the largest telescope now in existence. These several increases place the large telescope beyond the rach of precedent and tradition.

Not only were new ideas, new materials, and new methods imperative, but the new order of dimensions and conditions gave opportunity to exercise that ingenuity and a desire for progress, underlying every engineering heart worthy of the name.

The complete observatory consists of two main parts, one in Pasadena and the other on a mountain top. The executive office, laboratory building, machine shop, and optical shop were built at the California Institute of Technology.

Ninety miles to the South and East of Pasadena is the telescope site on Palomar Mountain. The two are connected by 130 miles of excellent level and good mountain roads. In 1938 the average driving time is three hours either way. Palomar was selected because of good seeing conditions and its distance from the sky illumination and distractions of the Los Angeles metropolitan area.

On Palomar are the utilities, consisting of a million-gallon reservoir, a tower tank, a small machine shop, and a diesel electric generating plant. One small telescope has been completed, while the 200-inch and a large Schmidt telescope, are now under construction at Palomar.

Introduction.—In this paper on arc welding I will describe the 200-inch telescope dome drive in detail, and endeavor to show something of the progress of the work, as a whole.

Preliminary work on this project was undertaken just prior to 1930. Work progressed in a small way with the building of machines for the

operations at Pasadena. We had had practically no experience in building machine parts by arc welding. All of our ingenuity was applied to the designing of these strange machines that were required for optical work.

When the 200-inch disc was at last assured, the organization was expanded, and the real work of actually building the 200-inch telescope was begun in earnest.

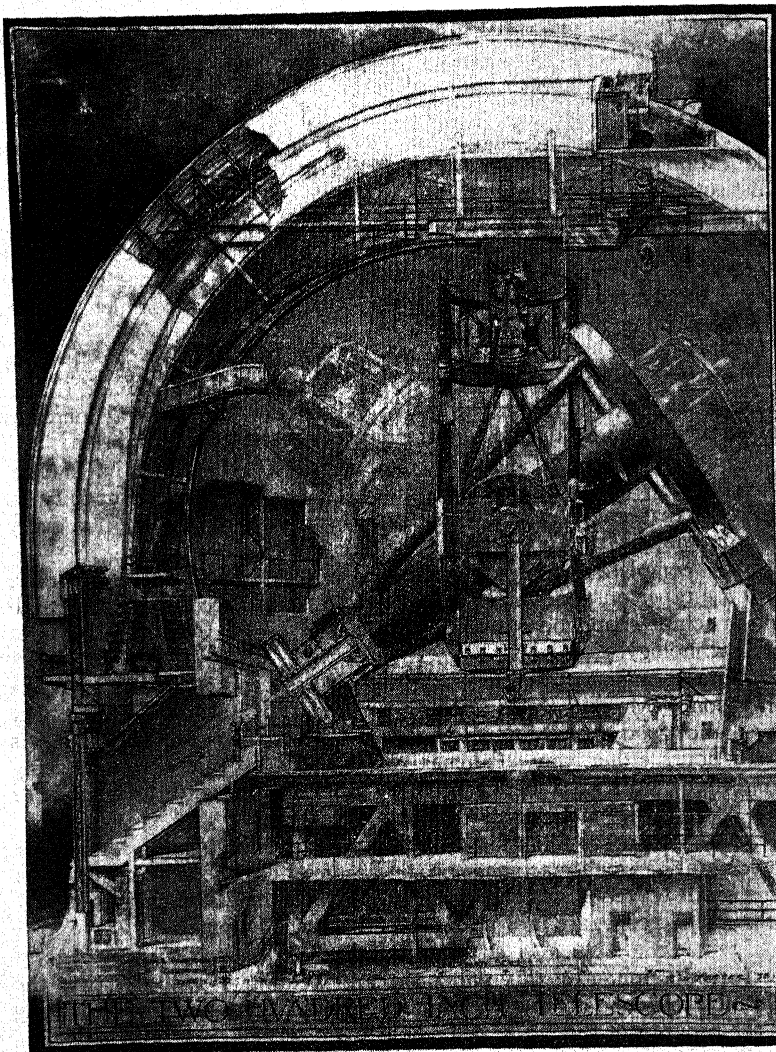

Fig. 1. Cross section through big dome showing general arrangement and th 200-inch telescope.

With this installation of new life it soon became apparent to us, of the original group, that arc welding applied to the design of machinery, held great possibilities. Arc welding was tried at first tentatively, then with more confidence, and now with a whole heart.

Let us see, then, how this evolutionary process has taken place, and what benefits have been derived.

Arc Welded Dome.—Telescope design in Southern California began to take on importance with the advent of the 100-inch telescope on Mt. Wilson. At that time arc welding was in its infancy. This dome, built more than two decades ago, was of riveted construction throughout. In

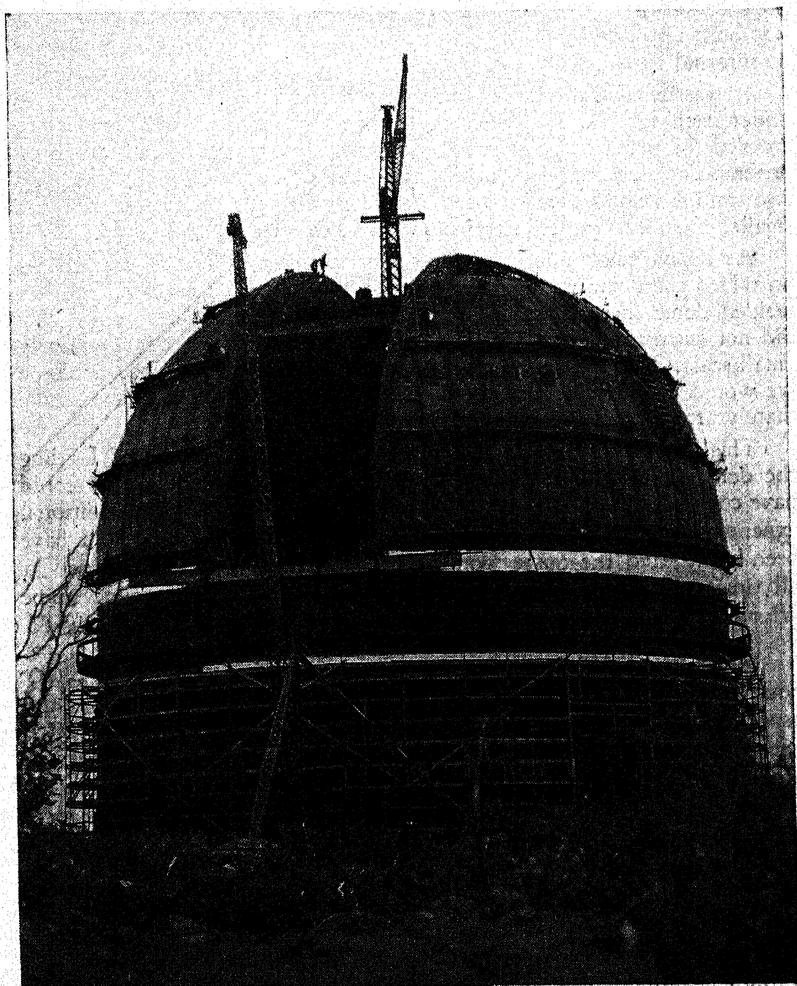

Fig. 2. Arc welding the 200-inch telescope dome.

lining up the trucks on this one hundred foot diameter dome, it was found necessary to run the structure around for weeks, until the joints had slipped all they were going to. In the meantime, the trucks were jacked back and forth, as first one and then another crowded against the rails. Finally, it was deemed safe to drill the dome and bolt the trucks in place.

One of the first rungs in our ladder was a twenty-foot dome to house a Schmidt telescope, the first astronomical instrument installed on Palomar Mountain. Here was our chance to try arc welding on a dome structure in a small way. We wished to find if there were any difficulties to be encountered in fabricating a spherical housing, such as a dome. The Schmidt dome was, in a small measure, a field laboratory for the design of the 137-foot diameter telescope housing. Bumped sheets were produced at the factory and shipped to the dome site. Here the structure was built up piece by piece with a shielded arc rod. The small dome has no internal ribs.

It was decided on the large dome, (See Fig. 2), to place small ribs under each seam and leave them in place in the final structure. This enabled the plates to be conveniently pulled into place, and no auxiliary or temporary structure was necessary. Otherwise the 200-inch telescope's two million pound dome is of the same monocaque construction as the smaller one. There were no rivets used in either dome.

As I have said, much adjusting was necessary to line up the trucks on which the dome revolves, in the case of a riveted structure. With a welded dome there is apparently no such readjustment necessary. We did not learn this from the Schmidt dome, the job being of a relatively small scale. Had we known for sure the dome would not change shape we would have bolted the trucks on the 200-inch telescope dome immediately after they were installed.

This would have saved employing an auxiliary method of holding the dome in high winds, and the crew who installed the trucks could have completed the job at once, instead of being called back at additional expense when no readjustment was found necessary. Time could have been saved, and the dome would have been more securely fastened at all times. Evidently large arc welded structures do not change shape after completion, when subject to movement, as much as riveted ones do.

Multiplicity of Units.—In 1930, when the smaller pieces of auxiliary equipment for the optical shop and laboratory were begun, welding, and especially arc welding, was not too well known. More recently coated rods have come into their own and given us a new and reliable method. This newer method of fabricating low-cost materials, such as rolled steel, believe me, we have welcomed with open arms. In looking back over some of our early machines one can easily see by comparison the advances and advantages obtained through arc welding at present.

There are an endless number of things that have been arc welded on this job: the 137-foot dome already mentioned, the telescope structure, the 200-inch grinding machine, the 120-inch grinding machine, a 48-inch grinding machine, a machine to hob the three fourteen-foot worm gears for the big telescope, the Schmidt telescope dome, test

stands, large micrometers, test beams, shop trucks, stands, platforms, and bases of all types. Each of these, and many other smaller pieces of equipment containing literally hundreds of parts, have been fabricated with arc welding.

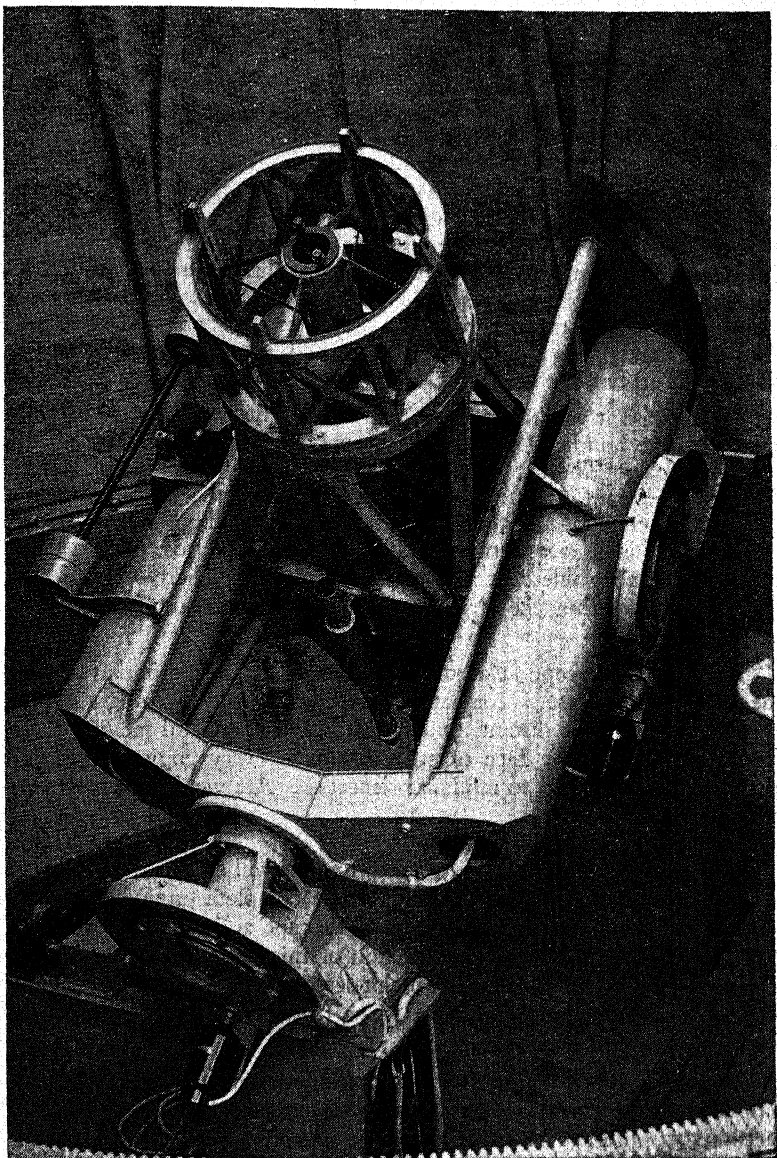

Fig. 3. Tenth scale model of 200-inch telescope.

The Telescope.—The 200-inch telescope's most noteworthy predecessor was the 100-inch at Mt. Wilson. Constructed twenty-five years apart, these two telescopes are typical of the engineering period in which they were built. The 100-inch is entirely riveted, bolted, and employs many castings. The 200-inch telescope, (See Fig. 3), while not altogether free from castings, is not at all riveted, and in appearance, is easily the most efficient structure yet designed for use as a large telescope.

The tube contains many surfaces that had to be machined. Consequently, it was built of units which could be shipped from the machine shop to the site. These units are bolted together, but the units themselves are arc welded. This enabled the engineer to place the material where it would provide the greatest rigidity. Strength itself, almost never enters into the design of a telescope proper. Arc welded butt joints provide a means of joining materials together to attain maximum rigidity. In riveted construction one must utilize joints that are not one hundred per cent efficient or carry the weights on cantilevers, which increases deflection. With a mirror ground to a surface departing only one millionth of an inch from a true paraboloid of revolution, even extremely minute deflections are ruled out.

In one case it was necessary to provide a cantilever pier, to support a load of five hundred pounds. While only seven feet high the base is 32 x 42 inches. The box section was arc welded from one-inch plates. This extremely stiff structure was necessary to keep the deflection below the required amount. Fastening the base by arc welding was absolutely necessary. Flange connections, either riveted or bolted, would have exceeded the allowable deflection at least five times. There were no jogs or cantilevers within the structure, and all of the material was used efficiently.

Pointing a telescope at a star and keeping the image immovable on the photographic plate, is comparable in accuracy with pointing a gun at an object eight miles distant, two inches in diameter, and moving three feet a second. In the face of such accuracy, every engineering trick available, must be used to minimize deflection. Arc welding is often the only solution.

Modern Design.—To build a machine that will still be modern fifty years from now, has been the goal of the complete engineering staff working on the design of the 200-inch telescope and auxiliary projects. All through the design and construction of this complicated project the above idea has persisted. The 200-inch telescope is an advance in machine and structural design, as well as a step forward from an optical and astronomical standpoint.

Accuracies never before attempted on a large scale are being accomplished. Contemporary to the attempts of commercial shops and manufacturers to produce hitherto unheard of precision, is the design of this instrument which is as much more precise as it is larger, than any existing machine or telescope.

We usher in a new era of "precision machine design." This new era is being made possible by the new materials and new methods of fabrication which have been developed through industrial competition. Not least among these has been arc welding.

New Design.—In laying out a new design the approach is usually, "What does a similar machine look like, what new developments lift the old restrictions?" And the first new development usually thought of is arc welding.

Arc welding is the answer to the desire for something light, strong, stiff, resilient and cheap, and with a versatility that lends itself to any design. Time after time on this job I have laid out the gears or levers, put the shafts in, supplied the necessary bearings and around them the supporting bosses, joined the bosses, and surrounded the moving parts with rolled steel at four cents a pound, and another arc welded structure takes shape on paper.

A saving of fifty per cent has frequently been effected. A casting has been laid out and then the job also designed for arc welding. Bids have been asked for both methods. Often the arc welded parts including stress relieving, have come to a little over half the cost of the casting. And the cope cannot float on a rolled section and double the weight on you.

Basis for Computing Costs.—All products for which costs are shown were not manufactured nor generally used before January 1, 1937.

The percentage saved by arc welding is calculated, by dividing the difference in cost between arc welded and cast construction, by the actual cost.

Unless otherwise noted in this paper costs are on the following basis: Casting prices are those net to us from the steel foundry. Rolled steel plates are figured at the price given, our shop, uncut. Pattern costs are time and material, the work being done by our steadily employed pattern makers. The welding is on the same basis of time and material by our regular welders. Any but easy bends in flat plates are sent out to a local blacksmith. Stress relieving is contracted out and also done in our own furnace, a small one.

In the case of welding versus casting, the cost given here is that of the industrial concern who must design equipment to be built in their own shop, but who do not themselves operate a steel foundry and must, consequently, buy castings.

The comparison here, however, is an equitable one for several reasons. The overhead on the steel castings purchased outside is about the same, as if a foundry were operated within the manufacturer's plant. The overhead is high mainly because a steel foundry entails much expensive equipment.

In comparing the costs of welding and casting, I have shown no overhead for either pattern making or welding labor, for the reason that we do not charge overhead in our accounting, and consequently, the figures are not available. The welding, however, includes all direct expense, and the costs were taken from our accounts.

Overhead, due to pattern shop equipment, is a little more than the overhead of welding equipment. Costs shown for pattern making and labor for welding, while not exactly equal, are quite comparable. The costs, therefore, show the true picture. Any factors omitted, if included, tend to increase the cost of casting use.

The Dome Trucks.—The two million pound dome is carried by 32 trucks, rolling on a circular track, under its periphery. Each four-wheel truck, (See Fig. 4), carries its 65,000-pound load, distributed over the central flange of the arc welded top bolster.

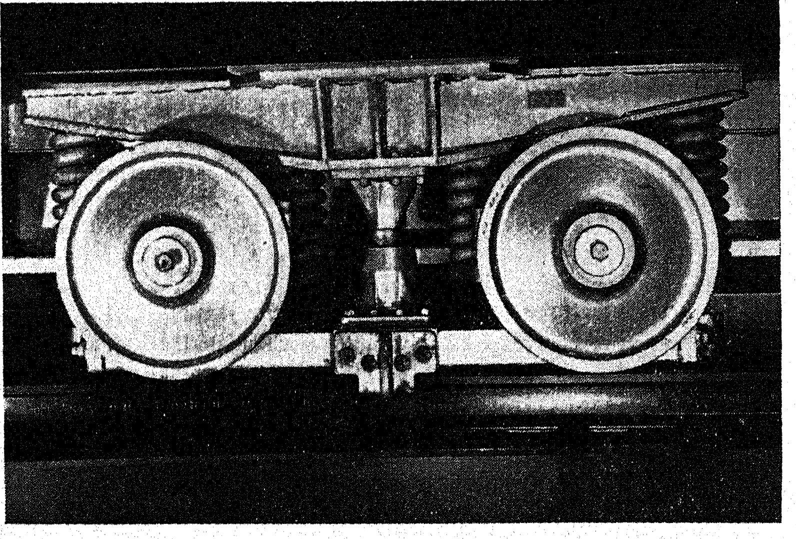

Fig. 4. One of 32 arc welded trucks which carry 2,000,000-pound dome.

These trucks were built under subcontracts let to local job shops, and the costs given are from bids submitted to us by these concerns. The largest piece, the top bolster, weighs nine hundred pounds and forms the backbone of the truck. The bids on this piece showed such contrast between arc welded and cast construction that we thought there had been a misunderstanding. However, both this and the lower frame, also arc welded, were built for us and delivered at the price quoted. The welding shop claims to have made a profit.

The welded parts are stronger, lighter, and have proven satisfactory. Modern in appearance, the design is good- and efficient-looking. The top frame was arc welded from sheared plates and an eight-inch pipe section. The bottom frame was produced from a heavy channel reinforced with bars. Stress relieving the sixty-four pieces at one time effected additional savings.

COST COMPARISON (DOME TRUCK)

	Arc Welded	Cast
Top Bolster (32 Required) @ $ 61.75	$1,976.00	
Top Bolster (32 Required) @ $102.38		$3,276.00
Lower Frame (32 Required) @ $31.88	1,020.00	
Lower Frame (32 Required) @ $63.09		2,019.00
Total Costs	$2,996.00	$5,295.00
Total Cost, Arc Welded		2,996.00
Saved by Arc Welding		$2,299.00

43.4% SAVED BY ARC WELDING

Shutter Trucks.—An opening in the big dome, 130′ x 30′, is covered and uncovered by two arc welded steel shutters, running on arc welded steel trucks. The trucks under the lower ends of the shutters carry not only the vertical weight of part of a shutter, but the entire wind load and horizontal earthquake shock reaction.

Here, the simultaneous carrying of two loads at right angles to each other, demands a box section for greatest efficiency. This was easily accomplished with bent bars, bosses cut from 4″ plates, and a number of 3/8″ sheared plates. We did not consider steel castings for this job, although my tabulations give the cost of cast construction.

The design involves large heavy bosses for the bearings, connected by relatively thin webbing, which in casting results in poor strength at the juncture of the bosses and the web. The only remedy in casting design is to use excessively thick sections. This increases the weight and the cost. Using a box section requires core boxes, baked cores, and additional expense in molding. There is no assurance that the parts will not be produced heavier than designed. Shrinkage, we have found in casting design, to be highly unpredictable. Some shrink according to the rule, and some, especially those with heavy cores, do not shrink at all.

The strength of those which do not shrink is open to suspicion. The hard cores prevent the steel from contracting, as it should do in cooling. It is a well known fact that stressing a metal at temperatures near the melting point, results in either a fracture or a porous and unreliable metal.

The pedestal piece, most of which cannot be seen in the assembled shutter truck, has an unusually large amount of overlaid arc welding. The center boss is 8″ in diameter and 5″ long. This was welded to ribs 1½″ thick, crossed with other ribs 1″ thick, by building up layer after layer of weld metal. The joints were veed to give one hundred per cent strength.

The design involves space limitations. It was necessary to know that the strength of the metal joining the boss to its ribs, is equal to that of the ribs. In casting, the strength at this critical point is problematical. By laying in the beads, one after the other, each one of reliable strength, the whole was built up to give a piece, of great strength and reliability. Should this particular weld fail, the 130′ shutter would pop off on the ground one hundred feet below.

Utilizing metal of good strength and good reliability enabled a com-

pact and efficient design. In this case, as in many others, using higher strength materials at the center or crucial part of a machine, often results in the overall dimension of the complete machine's being considerably reduced. Consequently, much time, material, labor and space, is saved which, of course, reduces the overall cost of the complete project.

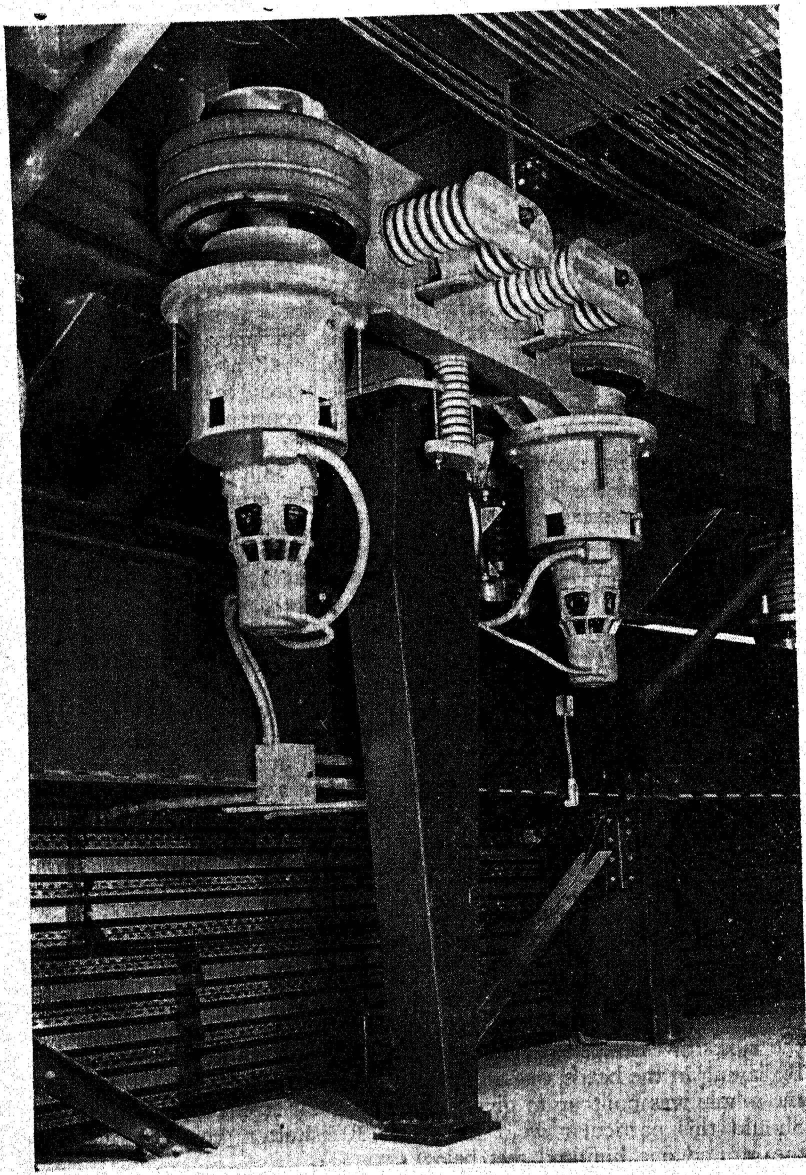

Fig. 5. Arc welded dome drive installed.

COST COMPARISON (SHUTTER TRUCK)

	Arc Welded	Cast
Pedestal (4 Required) @ $40.93	$163.72	
Pedestal (4 Required) @ $62.02		$248.08
Truck Frames (8 Required) @ $43.19	345.52	
Truck Frames (8 Required) @ $66.50		532.00
Total Costs	$509.24	$780.08
Total Cost, Arc Welded		509.24
Saved by Arc Welding		$270.84

36% SAVED BY ARC WELDING

Dome Drive.—In designing the foregoing units much was learned of the virtues of arc welding. In 1930, when the project was begun, we used no arc welding whatsoever, and then in each succeeding unit we used more and more welding and less and less casting. We only build special machinery for our own use and cannot, therefore, "redesign for arc welding." But we do read the handwriting on the wall and profit thereby. It has been said that a man's age is determined by the amount of pain with which he receives a new idea. When we discovered arc welding we shed a few years.

The dome drive, (See Fig. 5), is the last machine completed at this writing. There are four reasons why most of the parts are arc welded: feasibility, strength, lightness and cost, which I will explain in detail.

Being a new invention this drive has in its design stages been subject to considerable engineering derision. Knowing full well that the reputation of an engineer is made by a long series of successes, and that this same reputation may be broken by one failure, I was very careful to take no chances in any fundamental detail of the design. Aside from its basic idea the design is conservative. Stresses, probabilities, coefficients, and all other original assumptions were taken at their best average values. Arc welding was used, not only because it was cheaper, but because it afforded greater flexibility coupled with a more reliable design. This drive had to work—and it does work.

Dome Drive Pedestal.—The drive truck is supported and held in position by an arc welded pedestal, which is composed of three parts, the floor plate, the pedestal lower half, and the pedestal upper half. The floor plate is grouted permanently into the observing floor. The lower half sits on, and is bolted to both the floor plate and the arc welded stationary ring girder of the dome. The upper half carries the complicated rubber and steel vibration absorber and bolts directly on top of the lower half. Splitting the main part of the pedestal in two halves was necessary for assembly purposes. Fig. 6 shows fabrication of the upper pedestal by arc welding.

At first glance it might be thought that these parts could have been fabricated with riveted construction. Such was not the case, however, due to the manner in which the forces transmitted to the stationary ring girder, had to be taken care of. Three forces, all mutually at right angles to each other, are transmitted from the drive truck itself to the stationary part of the dome through this member. There is a force

tangential to the periphery of the dome, a horizontal one radial to the dome, and the five thousand pound vertical reaction due to the dead weight of the drive trucks. The tangential force not only produces bending of the pedestal but rotation as well. The other two forces produce bending.

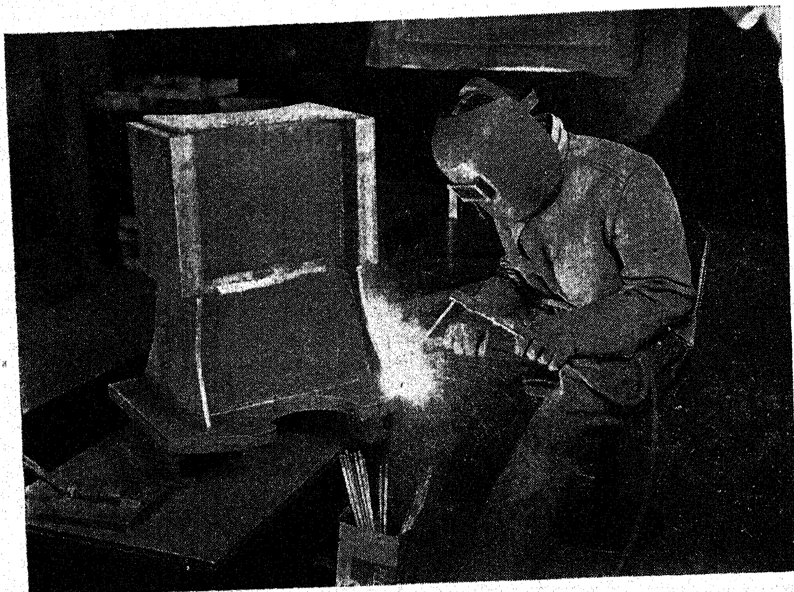

Fig. 6. Arc welding upper pedestal for dome drive.

Had not arc welding been available we would have been forced to cast all three of these members. The forces involved in the central flange could not have been taken care of by rivets without making the unit much larger and heavier. Space limitations and the loading required a box section with diaphragms. The tabulation of costs explains why it was welded and not cast.

Any saving in weight of the pedestal, or any part of the dome drive, results in additional savings, aside from that of the cost of material. The machine, of necessity, had to be assembled as completely as was possible in our machine shop in Pasadena. The partially assembled unit was then shipped to Palomar by truck.

Handling, blocking, trucking and unloading, were all facilitated by reductions in weight. The position occupied by this drive does not allow the use of the large crane. Temporary falls were employed in installing the drive in its functioning position. Weight reductions in all parts of the drive enabled using lighter equipment and speeding up the installation. Hastening this job allowed the dome to be rotated for painting with the eliminations of delay and cost in this rather expensive department. In the future, should repairs become necessary, dismount-

ing either one of these units will be aided by the lightness they possess. Delays will be avoided, and astronomers made happy sooner. The tying up of a six million dollar telescope will be avoided.

COST COMPARISONS (PEDESTAL)

	Arc Welded	Cast
Floor Plate (2 Required) @ $4.27	$ 8.54	
Floor Plate (2 Required) @ $8.21		$ 16.42
Lower Half (2 Required) @ $ 86.45	172.90	
Lower Half (2 Required) @ $232.60		465.20
Upper Half (2 Required) @ $37.07	74.14	
Upper Half (2 Required) @ $80.50		161.00
Total Costs	$255.58	$642.62
Total Cost, Arc Welded		255.58
Saved by Arc Welding		$387.04

60% SAVED BY ARC WELDING

Dome Drive Wheels.—When small diameter, but heavy wheels are fabricated by arc welding, less saving is effected than with the average job. This is true because all of the pieces but one are curved and consequently, harder to handle.

The rim was rolled from a ⅞″ plate 10″ wide. The disc was made conical from a ⅝″ plate, and the hub was 1½″ thick.

In spite of an excessive rolling charge of $19.00 per wheel, the arc welded pieces were cheaper than castings. The castings probably would

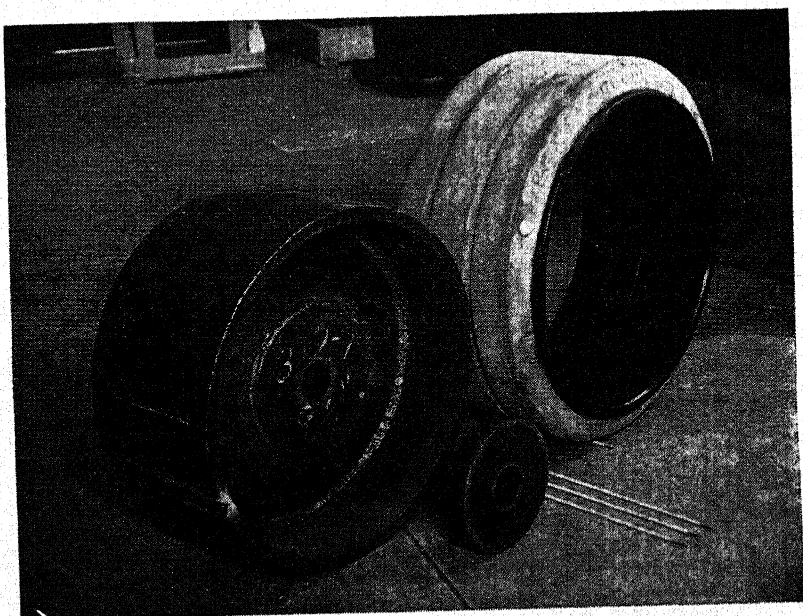

Fig. 7. Wheel completely arc welded just before machining.

have come heavier than the designed weight. We know it would not have been lighter. Castings never are.

The welded structure contains no sand, shrink holes, or embarrassing flaws where the thickness or shape changes suddenly. We know the joints are good, for the rim when machined showed no pinholes in any of the four wheels for the ten inches of weld. We know the welded piece is stronger than the casting in the ratio of 16,000 to 10,000 pounds per square inch. The twelve cents per pound for the casting is low for this class of work, but was offered to us and must be recorded as a contemporary price. It is evident, therefore, even in extreme conditions which are not obviously favorable to arc welding, the chances are that economies may still be effected.

The welded piece, when ready for machining, (See Fig. 7), weighed 250 pounds. The extra thirty-five pounds in the casting is for heavy fillets and ribs to aid in founding. The rolling job was a poor one and had to be corrected by hand labor. The accuracy with which the wheels were produced by the welder is shown by the even rim thickness in the finished wheel.

It is evident that in producing shapes which have heavy rolling, not much is to be gained until the technique of fabricating a part is perfected. Were these wheels to be produced again, an additional saving of fifty dollars would be effected.

COST COMPARISONS—WHEELS

Cast —(4 Required) @ $53.45	$213.80
Welded—(4 Required) @ 50.70	202.80
Saved by Arc Welding	$ 11.00

5½% SAVED BY ARC WELDING

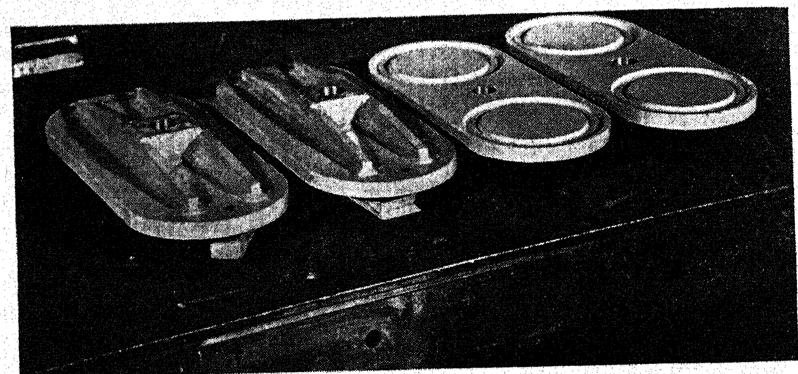

Fig. 8. Arc welded spring plates.

COST COMPARISON DOME DRIVE SPRING PLATE (See Fig. 8)

Cast —(8 Required) @ $14.40	$115.20
Welded—(8 Required) @ 6.20	49.60
Saved by Arc Welding	$ 65.60

56% SAVED BY ARC WELDING

Vibration Absorbers.—The drive units containing the wheels and motors are isolated by four vibration absorbers, (See Fig. 9), from the pedestals and, consequently, the stationary part of the dome. The isolation units, two to a drive, weigh two hundred pounds each and handle loads of seven to eight tons apiece. They are composed of alternate layers of rubber and appropriately shaped steel members. The alternate steel members are attached to the bolting flanges on one side of the unit. The other alternate rolled steel pieces are fitted to the shaft in the center. The loads are transmitted through the shaft to the plain steel plates; thence, through the rubber to the flanged steel plates, thereby transmitting all forces through the rubber. Part of the forces imparted to the steel shaft through the central plate are at right angles to those produced on the shaft ends by the spring links.

The steel members are of three different welded shapes, one merely flame cut, and one casting that should have been welded, as shown by the cost tabulation.

The rolled steel surfaces are true and of the proper smoothness to clamp the rubber sheets without any machining. As will be noted in the table, the casting weight is considerably more than the welded piece. The cast surface would not have been even enough to grip the one-half inch rubber sheets properly and would have to be finished. The finish metal accounts for the extra weight in casting.

COST COMPARISONS VIBRATION ABSORBERS

WELDED				CAST	
Number	Quantity	Each	Total	Each	Total
1	8	$1.30	$10.40	$ 8.05	$ 64.40
2	8	1.55	12.40	9.59	76.72
3	8	1.26	10.08	7.87	62.96
4	4	2.84	11.36	11.74	46.96
Totals			$44.24		$251.04
					44.24
Saved by Arc Welding					$206.80

82% SAVED BY ARC WELDING

Truck Frame.—The main structure of the truck itself could not possibly have been constructed by any other means than arc welding, without employing an entirely different, and certainly less satisfactorily shaped frame. Here, arc welding allowed the engineer to design a graceful, compact and efficient structure. (See Fig. 10).

The design has been worked out so that unit assemblies were made, and then each assembly in turn was welded into the main structure. All inside joints were arc welded to give a maximum of rigidity and strength before the stressed cover plate was welded on. Slots were left

in this cover plate to enable the arc welding of the ribs in the slots, by filling said slots flush.

Uniform wall thicknesses of ¼″ are obtained in no other method practical, except with arc welding. The fiber stresses may be calculated at 16,000 pounds per square inch for SAE 1020 rolled steel, instead of 10,000 pounds per square inch for cast SAE 1020. The engineer

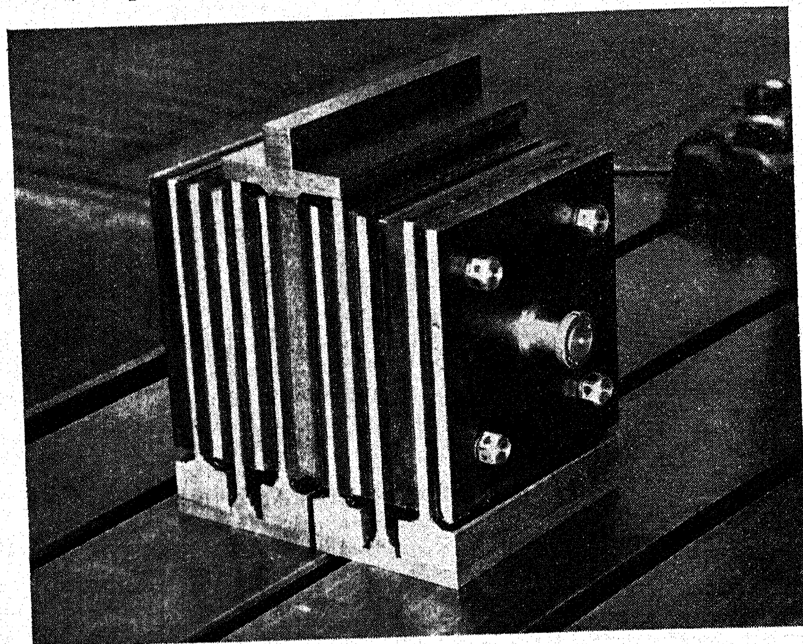

Fig. 9. Arc welded vibration absorber.

knows the wall thickness, for arc welded jobs will be as specified within approximately .005 of an inch, and he may, therefore, proceed with confidence. Where one wishes to control and minimize weight using thin sections and efficient shapes, only arc welding will do.

Much speed was made in arc welded assembling when all the component parts were straight. When curved pieces were used they often had to be pulled into place. This lessened the wide difference in cost between arc welding and other methods of construction. Straight rolled sections, of course, are as easily sewn together with the arc as flat plates.

A heavy bedplate to which the work was clamped quickened the job. The pieces were lined up, clamped down, and the arc joined them together at an amazing rate. A small hoist was used to turn the heavy work over in order to employ down arc welding. Welding in deep corners was avoided where possible, in the interest of welding rod economy. We were unable to avoid a few pockets. The remarks made by the welder before welding the pockets did not seem justified in the light of the comparative ease with which the welds were made. Inspection showed them to be satisfactory and apparently little different

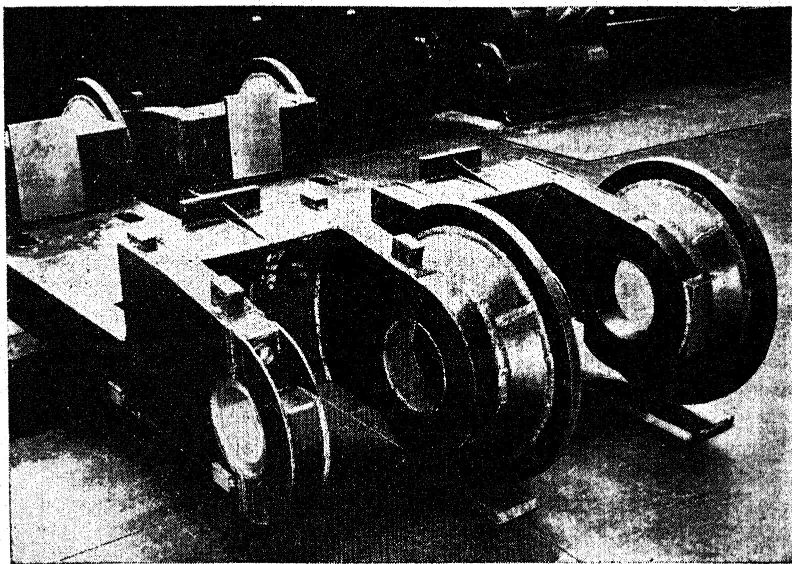

Fig. 10. Arc welded drive truck frame.

from other welds. As is often the case with new methods of performing a task the complaint comes first, then the task is performed, the operator gets used to it, and later thinks nothing of it. Engineers think of difficult ways of doing things better, and good shop men learn to do them more easily. Once the technique has been mastered it is merely a matter of turning the crank. Such is progress.

COST COMPARISONS (DOME DRIVE TRUCK FRAME)

Arc Welded (2 Required)

Each—1527 lbs. of plates @ 4.1¢ per lb.	$ 62.61
Welding and forming	101.50
Cutting	30.25
Gas—Acetylene 145 lbs. @ 3.35¢	4.86
Oxygen 990 lbs. @ 1.10¢	10.89
50 lbs. coated rod	10.00
Forging jobbed out	10.00
83 KWH @ .88¢ per KWH	.73

Cast Construction (2 Required)

Each—2300 lbs. @ 10¢ per lb.	$230.00
Pattern $175.00 + 2 = cost per casting	87.50

ESTIMATED TOTAL COST EACH	$317.50
ACTUAL TOTAL COST EACH	$230.84
Saved by Arc Welding	$ 86.66

38% SAVED BY ARC WELDING

Remarks on the Welding of the Drive Truck.—The machine shop, where the work on the dome drive was done, is primarily an instrument shop. Working at a medium pace each operation is carefully performed, and more than the usual amount of care is taken to produce a good looking job. This sometimes entails unnecessary work, but is thought to be worthwhile to prevent the workmen from falling into habits which are below those high standards, required in building machines of instrumental accuracy.

The number of machines under construction at one time of instrument quality varies considerably with time. Our shop was built, not only to assist in building the big telescope, but as a standby shop to produce from time to time the new instruments developed by, and required for, a schedule of astrophysical research, with the 200-inch telescope and the assisting equipment.

The machines built by us, while better than those obtainable in contemporary shops, have entailed more man hours than if built by men working under profit-making pressure. One may notice in the photograph how extremely true and even the wall thicknesses between a rough and a finished surface appear.

In comparing the cost of these machines the omission of an overhead charge is practically compensated for by the slower working rate of our precise atmosphere. Costs in commercial shops including overhead will be very close to those given in this paper.

Cutting the circular flanges from square plates involves considerable waste of material. It has been mentioned elsewhere how this material may be used.

The cone was cut originally in one piece and then rolled into the shape shown in Fig. 11. It would have been more economical to cut the cone in four identical parts and roll these separately. It was found that the welding would be carried on more satisfactorily by cutting slots in the cone anyway. Cutting four separate pieces originally would have saved material and rendered the forging operation much simpler. The same procedure should have been employed in welding the wheels.

The cone was employed even though more difficult, than cylindrical or flat shapes, because of its rigidity and lightness, and because it suited this particular situation.

Heretofore, we have not used cones in any of our construction and were not familiar with the tricks necessary, to economically employ this very useful shape. As I have said, should we again build a similar machine, the cost involved in the use of cones and heavy rolled plates would be considerably reduced.

While progress is being made we still are not up to date in our use of arc welding. One instance of this is shown by the weight of welds employed. For simplicity's sake in making drawings, the size of welds has been omitted, except in crucial places. In the majority of instances the welds laid down are very much stronger than necessary to carry the loads. There are two reasons for this. First, the strength of welds has been steadily increasing. Tradition goes by strengths the workmen have been accustomed to. Therefore, the welds are in some cases even ridiculously strong. However, the actual cost of laying in the

bead is a minor one, and we have not gone to the trouble to control the size of the weld. The second reason for excess strength is continuous welding which in many cases aids appearance. It will merely be a matter of getting used to looking at intermittent welds to consider them acceptable in appearance.

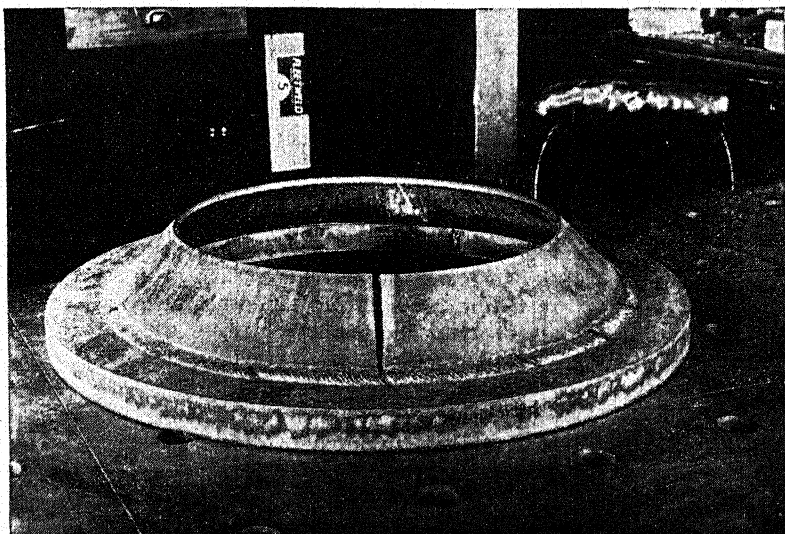

Fig. 11. Building up motor mounting flange. (See Figs. 5 and 10.)

Savings on Spot Facing Due to Arc Welding.—The spot facing of bolt holes can be eliminated in a large percentage of cases by the use of arc welding. All bolt holes which do not occur in a finished area on a casting must be spot faced. In finishing a welded part, unless the weld itself encroaches on the area occupied by the nut or washer, spot facing is often unnecessary, with resulting saving of machining costs due to the use of arc welding.

The pedestal upper half shown in Fig. 6 is a good example. The surfaces of rolled steel are obviously smooth enough to properly seat a bolt head, washer or nut. It is only necessary to design the piece properly and avoid tipping these surfaces out of square when welding. Thirty-two bolts were drilled for, and only four of them needed to be spot faced.

The pedestal lower half contains thirty bolt holes, none of which were spot faced. The floor plate contains four holes for bolts which would have been spot faced for bolt heads.

Spot facing is frequently a slow process. Many holes can only be drilled from one side. If only the hole has to be drilled this is easily accomplished. If it is necessary to spot face, the tool must be inserted in the boring bar from the rear and removed again for each new hole. Such would have been the case in all of the holes mentioned above except those in the floor plate.

There is no industry that a saving in spot facing would not effect. Eliminating this often troublesome procedure, will save millions of dollars to industry—another contribution by arc welding.

Arc Welding Advantages Apply to All Industry.—It may be pointed out with a certain amount of truth, that relatively few telescope projects are ever undertaken. I would, therefore, like to point out the similarity between building heavy machinery for this project, and the type of machinery built in great quantities throughout industry.

Many manufacturers build special machinery for themselves or for their customers. The quantities produced do not justify any great amount of research or extensive refinements through trial and error of design. The machines must work properly as initially designed, and only a few are built from the original drawings. With this type of machinery reliability is of paramount importance.

Pioneering machines, or special machines of any type, involve a greater unpredictability of loads and conditions than ordinary production machinery. Any failure occurring to these machines will usually involve a greater loss of time and money, because they are special and take longer to replace. Due to their special nature, failure may often involve loss of life; hence, reliability is again of great importance.

A considerable amount of energy will be absorbed by a steel part before it fails so completely, as to endanger the rest of the machine or the life of the operator. For this reason, we seldom feel justified in using cast iron. Consequently, we have made no comparison with the cost of this generally not so reliable material. Weight is often a factor and, therefore, cast iron again is barred.

Steel is the only material that will supply the necessary reliability. Arc welding is the only method whereby steel may be fabricated in a completely predictable and reliable manner.

Each industry has its field of application for the type of construction described in this paper. The personnel of each industry will be able to think of many such applications. Among those are in general: special boring machines, especially the portable type, large door operating machinery, trucks and movement mechanisms, plant, handling equipment, mine equipment, bases, bearings, bosses, bed plates, brackets, gears, gear cases, wheels, excavators, dredging machinery, canal lock machinery, hydro-electric machinery, pile driving machinery, bending machines, hammers, presses, punches, car pushers, cranes, derricks, elevators, mechanical bridges, hoists, sorting machines, crushing machinery, plant and interplant tractors, a great number of parts of oil well drilling equipment, and ship operating machinery. Shipyards, especially, must build special equipment to do their particular type of work. They are often able to build these machines in their own shops after their own design, and save money over buying a piece of production equipment that does not exactly suit their needs.

Developments are going on at an increasingly faster rate. Machines are being required that were never heard of before. Many of these are practically impossible to produce by any other, than the arc welding method.

Quite the contrary to being a field in itself, the building of heavy machinery such as found in this telescope project, is representative of practically the whole of industry. Costs and conditions, therefore, apply to the whole of industry. The gross savings, the individual savings, the general advantages, and all of the special advantages enumerated and discussed at length in this paper, applies to all industry. The total savings and advantages are, therefore, limited only by the amount that these arguments are heeded by engineers everywhere.

General Advantages of Arc Welding.—Operating on a schedule that requires each machine to be put into service at the required time, lays stress on reliability of methods of fabrication. By building a machine in our own shop we increase the probability that the machine will be done on time. This is especially true with arc welding. In building an arc welded structure, all of the work is done in our own shop and is, therefore, controlled. Patterns do not have to be sent out, outside bids do not have to be obtained, the job does not have to be

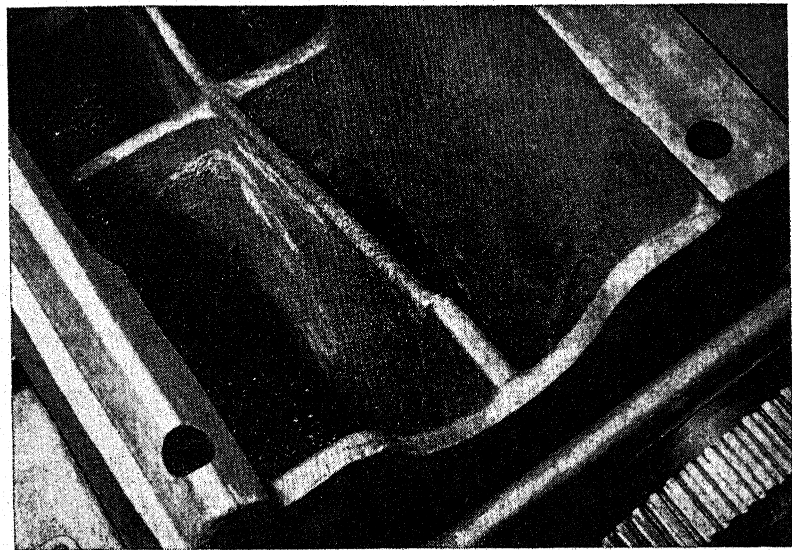

Fig. 12. An imperfect casting.

fitted in with a schedule of another plant, and finally, the piece does not have to be brought back to our shop. A welded piece may be obtained in only a little more than the time required to perform the labor, whereas, a casting may take over a week to be produced and brought back to the shop.

Another hazard eliminated by the use of arc welded parts is the probability of time lost, should a casting prove faulty as in Fig. 12. When a casting is returned to our shop, inspection may reveal immediately that the casting will not do. We must then confer with the

foundry, obtain an adjustment, and either weld the piece or reject it entirely, and order a new one. If the part passes the initial inspection it is, of course, given to the machinist. After considerable machining, time, and actual hard dollars are expended on the part, a flaw may appear that will necessitate a final rejection.

The wheels for the big dome shutter lower trucks were cast in SAE 1055 and annealed. On machining the tread one of the eight was rejected due to flaws, and three more were seriously discussed but finally accepted. Had they been SAE 1020 we would have saved them by arc welding, but the 1055 casting was not a suitable candidate for such treatment.

The main spindle housing for our 120″ grinding machine was cast in SAE 1020. Upon machining this several hundred pound casting, a circular flaw was revealed completely around the periphery. The casting was saved by arc welding for less than it would have cost to truck the faulty piece back to the foundry. An adjustment was obtained.

Some castings at an advance stage of machining may be saved by arc welding the flaws. In this case the part will warp out of true, and additional machining will be required. If the machining is at such an advanced stage that the finished part will be smaller than specified, a rejection must occur, or subsequent parts altered with resulting loss of time and money.

In order to be certain of getting a machine out when needed and at a predictable cost, we have adopted arc welding.

When casting, samples are often produced for testing the properties of the metal. Much ingenuity has been exercised in attaching these test bars to the main castings, in such a manner that the test bar will actually indicate the reliability and properties of the metal in the casting. The difficulty is that no amount of ingenuity will insure the test bars being the same as the casting. In spending money on testing cast samples one is paying for something he does not get. You pay your money and hope for the best. With welding you do not have to pay your money on test samples, and you do not have to worry because the physical properties of the rolled materials are well standardized and completely reliable.

Arc welding reduces trucking costs to a bare minimum. Rolled material may be purchased in large quantities at the lowest cost per pound, and with one telephone conversation. The material will be delivered by one truck and one driver on one trip. Buying castings involves the agreeing on the price per pound for castings, the price being different for castings of different weights. The pattern must be sent to the foundry, the time predicted when the castings will be ready, and then picked up in small batches, so that machining can be started without too much delay. These various steps result in an unpredictability of when machining may start. With a welded job machining may, at no additional expense for trucking, begin on the first part as soon as one is turned out by the welder. Managerial headache and attention is thus reserved for more important matters.

Management is usually conservative and does not take chances; hence, patterns are often kept on hand just in case a part fails, and a

duplicate is needed. Not only do welded parts fail less often than castings, but welded parts can be rewelded more easily, and their strength increased. The casting, especially cast iron, must be remanufactured.

A welded part is easier to repair than a casting because castings are rounded, and applying reinforcing straps involves bending them first; a welded piece is usually straight in all of its elements.

The maintenance of a pattern loft must be charged directly to the use of castings. The added burden on management of maintaining an index, the cost of shelves, the added floor space, the added heating and ventilating, and the added depreciation of patterns re-used, must all be charged to this method of building machinery.

Much material is apparently wasted which can be used and should, therefore, be deducted from original costs of material. In cutting circles from rolled plate, the corners, and the hole in the doughnut as it were, are charged in this analysis to the cost of the original piece. However, in a shop such as ours, and many found throughout industry, that makes all sorts of objects large and small from rolled steel, these left-overs are soon used. Not only in this a tangible saving in the cost of buying new material but also an intangible one.

A toolmaker or a machinist may want a jig or a fixture. He goes to the welding shop, sorts over the pile, selects a piece, marks with his chalk, and requests the welder, "Cut this out so, and weld this on thus." He does not have to think through his requirements in thin air, order the material, or cut it out of new stock, but instead he goes right ahead and gets his part from scrap without hesitation. He knows scrap is cheap and does not hesitate to use it. If he had to order a new plate or bar the price per pound would be much higher than was paid for the scrap, which was a part of a large order. If he took his material from stock he would be more apt to hesitate in order to conserve material which he knew had a real value. The reduction of extra thinking and planning which the toolmaker is not especially fitted to do again results in the saving of time, money, and general delay—another saving by arc welding.

The truck frame itself, as well as the wheels, spring plate, vibration absorbers, and the pedestal upper half, were all considerably lighter, than if these parts had been cast. Total saving of unsprung weight per unit was about 1400 pounds. It was highly desirable that the completed truck including the parts mentioned, as well as the motors, be assembled in our instrument shop at Pasadena. This was done, the drive sent to Palomar on a truck, and installed in the dome. In Pasadena, we had skilled technicians who were capable of assembling this machine. On Palomar there was seldom any necessity for this type of labor. Sending this part of the machine in one piece enabled the construction men to merely hoist and bolt the machine in place.

The installation was in an awkward place. This operation, and any subsequent overhauling, is greatly facilitated by any reduction in weight. There is more difference in weight than is shown by the cost tabulation, as the total amount of material ordered for the welded piece is given. Approximately thirty per cent of this was cut from the final weight before machining.

A more important factor than facilitating handling mentioned above is the effect of weight on the resilient mounting. The weight relieving spring is mounted in such a manner that the bottom travels transversely with respect to the top of the spring, as the truck unit moves in and out, due to irregularities of the dome surface. The size of this spring builds up very rapidly and awkwardly with increase of weight. The lighter the spring, the less force is required to move the truck unit in and out, which effects the evenness of the drive.

A lower power-weight ratio enables a more efficient design of the vibration dampeners. Better control of both the vibration of the motors and the inherent runout of the rubber tires, slight though it is, is obtained. Here, as in an automobile, the reduction of unsprung weight is an advantage. The result is better ride control, and in our case, in less vibration's being transmitted to the telescope. It is thought that we may have to install hydraulic shock absorbers on these units. Using arc welding and consequently reducing the overall weight and, therefore, the magnitude of control necessary, results in reducing the probability of additional dampening's being necessary. Vibration control in the case of a telescope is completely beyond the realm of that found anywhere else in industry. When the telescope is running, following a star, and the image focused on the coude slit, we have a moving optical lever arm of six thousand inches. The slit itself is only 1/1000 of an inch wide. The diameter of the star image due to diffusion may be about the same magnitude. If an angular vibration of $\frac{1}{6{,}000{,}000}$ occurs the image will be thrown completely off the slit, and no light will enter the spectograph. Just to furnish a concrete example of what this means, a spectroheliograph was being operated near Cal. Tech by the late Dr. Hale. Results suddenly became impossible to obtain. Investigation finally revealed that a 1½ horsepower cement mixer two blocks away was disturbing the long focal length instrument.

The dome drive is the only piece of machinery that must run when the telescope is making an exposure, besides the clockdrive itself. The reduction of vibration as may be seen was very important in this drive.

Savings by New Use of Pattern Shop.—As the use of arc welded parts increase the number of patterns required, grows less and less. In our shop instead of laying off the pattern makers we have set them to building those numerous benches, shelves, cabinets, tool containers, and various and sundry aids to getting the work done better and faster, and with less tax on nerves due to errors and inconvenience.

Due to the magnitude of savings by using arc welded parts instead of castings we could even profitably let the pattern maker go fishing and pay him to do so. However, we have paved the roads to new efficiency, perfections, precisions and savings in cost, by utilizing our pattern maker's time in building modern objects instead of ancient ones.

Consultation on Design.—My contacts with the industries catering to cash customers has brought a very important fact to life. Customers will actually favor a weaker casting in preference to a stronger arc

welded part because the welded one looks so much lighter, and in their minds, weaker.

There are two ways to obviate this situation. One, which is not particularly scientific but is effective in some cases, involves merely laying in an extra heavy bead of weld metal.

The second method is more scientific and will cover practically all conditions. Change the design so as to utilize thin plates and arc weld them into a closed rectangular section. This not only makes the part stronger and lighter, but it also looks stronger. Grinding the weld smooth on the exterior corners tends to increase the effect of solidity.

This is not tricking the customer. It is enabling him to take advantage of a better product with a clear conscience in spite of his traditions.

Conclusion.—In designing the heavy machinery for the 200-inch telescope project I have unconsciously followed the advice to change over gradually. Some of the earlier machines were all castings and no arc welding. By the time we had come to the big dome some cast and some arc welded parts were used. Prices on both types of construction brought home the advantages to be gained, and now at the end of the job as far as the heavy dome machinery is concerned, practically all of the parts are produced by arc welding.

Only a given amount of money has been allotted for the 200-inch telescope project. Any saving effected in the primary and fundamental structure will show up at the end of the job. The more refinements that can be built for the telescope in the way of instruments for taking photographic records, as well as equipment for more fully interpreting the results obtained, will add tremendously to the service the project will eventually render the world. The work done by scientists in chasing down fundamental discoveries today will determine the everyday lives of people, throughout civilization ten to fifty years from today. The first man to look through a telescope was almost hanged for telling what he saw. Popular conceptions have made progress since that day, but astronomy is still not given full credit for its place in the advancement of knowledge.

The service arc welding will render to the world by saving costs on this project will be invaluable to society in the future. Should a 300-inch telescope be built, arc welding will play an even greater part than it has for the 200-inch project.

Chapter XXIX—Arc Welded Machine for Oxidizing Roast of Pyritic, Gold-Bearing Ore

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It is true that roasters have been in use for hundreds of years, but the design presented in this paper is quite novel. As pointed out hereinafter, roasters, and particularly this type of roaster, have a variety of uses. To pin the descriptions down definitely, it will be considered that this machine is for the purpose of an oxidizing roast of pyritic, gold-bearing ore,—25 tons per day of 24 hours.

Present State of the Art.—There are three general types of roasters now in use: TYPE A. This is a brick structure, in the form of a masonry tunnel, on the floor of which rabbles, or rakes, slowly scrape the ore forward to the discharge end. A firebox with grate, burning coal or other suitable fuel, is direct-connected to the roasting tunnel or chamber so that the flame plays over the ore, with the air for oxidizing same. This was the first general type of roaster. In its best form, it was in use at the Argo Smelter in Denver, Colorado, about 40 years ago. A modified type is in use at Cripple Creek, Colorado, and in various forms it will still be found as the predominant type at most smelters.

TYPE B. The Herreschoff type is essentially a vertical cylinder with a number of horizontal shelves, the ore starting at the top and being carried around and gradually down by rabbles until it is discharged, roasted, at the bottom. A 25-ton Herreschoff costs about $10,000. The air is fed in at various points through hollow shafting. Most of the flame is sent in at the bottom, which is consequently the hottest part. The consumption of fuel is very low, due to using the heat over and over again as convection carries the hot gases upward, thus heating the ore at each shelf. The roaster has several disadvantages, among which may be mentioned high cost; cannot use hot blast, (air is used to cool the shafting); heavy wear on rabbles; difficulty of getting exact adjustment of air and flame on individual shelves.

TYPE C. Has revolving cylinders. The body of cylinder is made of cast iron or steel plates riveted. Lining of firebrick is put in, and usually four rows of brick are allowed to project, spaced ninety degrees apart, to "roll" or tumble the ore as the cylinder revolves. A quite general price for this sort of revolving roaster is $6,000. Type C is coming into great general favor, and bids fair to replace types A and B. In spite of its rising popularity it has a number of serious disadvantages: Local regulation of heat and draft is almost impossible; the flame and air enter one end of the roaster and go out the other, which is of course against differential adjustments; for the average ore, the scouring action on the lining is great; the machine is heavy and unwieldy, a 25-ton roaster weighing 11 to 20 tons—this makes transportation difficult and

requires considerable power to turn the entire cylinder. These roasters use for fuel, coal, oil, gas, electricity or almost any flame.

We may also mention in passing, the Nicholson, which is a sheet iron oven with flame in lower compartment and air in the upper, with the ore stirred by paddles, back and forth and then periodically ahead. This is really a special form of Type A. A laboratory size machine is on exhibit at Boulder, Colorado, and a 25-ton a day machine would cost about $8,000. It has many inherent advantages, differential control of flame and air (by a number of slots for entrance at various points); the ore agitation is excellent. Among disadvantages,—the paddle activating apparatus is complicated and involves both watching and heavy repairs; the sheet iron wear is heavy for some ores.

The "Flash" roaster, which is a special form of Type B, plunges the finely ground ore into a vertical column of flame, roasting almost instantaneously. Experiments in New Mexico are said to indicate a fair success with the particular kind of ore being experimented upon there. Some of the disadvantages would appear to be that the ore would have to be crushed very fine, (an insuperable disadvantage for some cases); there is obtained only a one-temperature roast, no differential adjustment whatever, and a mild or sulfating roast is apparently out of the question.

The "Muckle" roaster is the development of an idea of a Denver, Colorado, inventor. He attaches onto the feed end of revolving cylinder (Type C), a combustion chamber so designed that the flame, given a rotary motion, heats the inner surface of the cylinder. This has the advantage of localizing the heat at the exact point needed, but differential adjustment is out of the question, practically the whole inner shell from one end to the other is the same temperature.

Another form of Type C is an electric roaster in which resistance wires are buried in the inner fireclay shell of the revolving cylinder to supply the heat. Differential adjustment of heat and air are practically impossible, although an even degree of heat is uniformly spread over the inner surface of cylinder.

There are some special roasters not covered in the above description, but the three types, as presented, give a good general view of the present state of the art, and of the more modern improvements.

Type D Roaster.—The purpose of this paper is to present a fourth type of roaster which we will call the Type D machine.

Its design is intended to correct the defects of the three other types and to present some advantages not to be found in any of the others. The idea of Type D is to supply a stationary cylindrical shell, with movable stirrer or blades to turn the ore over and over. Stationary shell enables the flame and air to be introduced down the entire length of the cylinder, so as to secure exact differential adjustment of both at every point of the roaster. Peepholes are provided so as to enable operator to see progress of the process at all points. This Type D Roaster possesses a great many advantages over all the others. We will go into these advantages in detail after first considering another item, namely, the importance of roasters in the economic field.

Importance of Roasters.—Formerly smelting was the normal method of extracting gold and silver from their ores. With the advent of the

chlorination process, and later of cyanide, this was changed. Gold could be extracted more cheaply, more quickly, by roasting and then cyaniding. As mines became progressively deeper and deeper, the ores became increasingly complex. Some ores that were easily amenable to "raw" cyaniding, amalgamation, chlorination, or smelting, did not need the preliminary roast, but these deeper ores, more complex, required roasting, not only as a preliminary to smelting, but later to enable easy and economical extraction by cyanide.

Probably, it is not an overstatement to say that within the next ten years of 90 percent of all gold and silver ores will require roasting as preliminary to subsequent treatment, cyaniding, etc.

Gold ores usually contain other valuable metals, such as copper, zinc or lead. A roast is required to put the ore in such shape that these values can be leached out or smelted to enable the extraction of all the values.

This matter of extracting all the values instead of being satisfied with merely the gold and silver has proceeded to such an extent that even the iron is obtained by roasting and converting into sponge iron. Two such plants are now being installed in the Northwestern United States—so the writer is credibly informed.

The same reasoning applies to the extraction of silver from its ores. The deeper and more complex ores of silver now require roasting as a necessary "opening up" to enable the extraction of the silver.

The great bulk of copper now being mined comes up in the form of sulfide and complex ores, almost invariably containing gold and silver, sometimes with other metals. The copper is extracted either by smelting, (preferably by reverberatories now-a-days), or leaching and electrolysis. In either case, for 90 percent of the ores, roasting is a necessary preliminary.

The standard treatment of zinc sulfide ores, (now over ¾ of the zinc ores), is to roast to zinc oxide and then smelt with carbon or carbon monoxide. The alternative treatment, is to roast to zinc sulphate, leach and electrolyze, thus requiring roasting in either event.

Smelting is still the standard method of extracting lead, but the lead ore must first be roasted.

Sweden has been making sponge iron for a great many years. In 1936 and 1937, the United States imported from Sweden about 3800 long tons of sponge iron, valued at about $120,000. This is evidently only a fraction of the total production of sponge iron in the world. Figures are not available for the exact quantity.

The two plants now being installed in the Pacific Northwest expect to turn out about 100 tons per day each when they arrive at full production.

A careful investigation over a period of years has convinced many that the foregoing is only the beginning and that in the not-distant future most of the iron and steel, of the world will be produced from pyrite.

The making of sponge iron from pyrite requires first an oxidizing roast and then a reducing roast. The making of sponge iron from hematite and magnetite needs no oxidation roast but does necessitate the reducing roast. In either event the "roaster" is a necessity.

Not all styles of roasters can function to make sponge iron. Type D, the roaster discussed in this paper, is eminently adapted for making both kinds of roast and therefore for the production of sponge iron from either pyrite or hematite.

The year 1937 recorded a production of nearly three million tons of sulphur in the United States, with a market value of about 1c per pound. World production is over twice this amount.

The sulphur thus far has come mostly from sulphur beds in Louisiana, Texas, etc., but these are becoming exhausted or increasingly difficult to extract—largely due to depth increase, and lower grade "heads."

The sulphur of the future must come more and more from pyrite.

This, again, means roasting for extraction; either a non-oxidizing roast, that is to say, volatilization, or an oxidizing roast followed by reduction through hot carbon, (Carpenter process, patented around 1900).

Sulphuric acid is made from pyrite by roasting. Copper and iron sulphates, and other sulphates are likewise produced directly or indirectly from roasting of pyrite, etc. The figures on production of sulphuric acid and the sulphates are not available, but are undoubtedly large.

In converting coking coal into coke and gas and also extracting the other by-products, the old wasteful method of direct burning in ovens is being gradually discarded. Modern practice requires "roasting" by electricity or otherwise. The Type D roaster, with some slight changes in design, is admirably adapted to this purpose.

Making carbon for filtering and purifying water can be accomplished nicely on Type D roaster, with a non-oxidizing roast.

Among other possible uses may be listed: (a), Burning lime from limestone, continuous production instead of intermittent; the heat regulation of Type D roaster is admirably suited to this purpose; (b), Making cement clinker is another use; (c), Drying ores, metallurgical products, etc.; (d), Incineration of garbage.

To obtain some idea of yearly value of products which may at some time in the future be handled by Type D roaster, let us take the recorded or estimated annual value and divide by two. This will give us something like the following:

Gold and Silver (rough)	$ 500,000,000.
Copper	100,000,000.
Zinc	30,000,000.
Lead	30,000,000.
Iron (and Steel)	2,000,000,000.
Sulphur	50,000,000.
Miscellaneous	100,000,000.
Total	$2,810,000,000.

When we remember that we have already divided the present production figures by two, and have not included many items in the total, it is not unreasonable to suppose that within the next five years roasters will serve world industry to the extent of a product value of over one billion dollars per year.

While exact data are not available, the experience of a competent engineer, (whose name is withheld at his request), over forty years in the metallurgical business, and extensive travel during that period, leads him to believe that roasters are at present serving an annual production of more than $500,000,000. This observation, taken in connection with

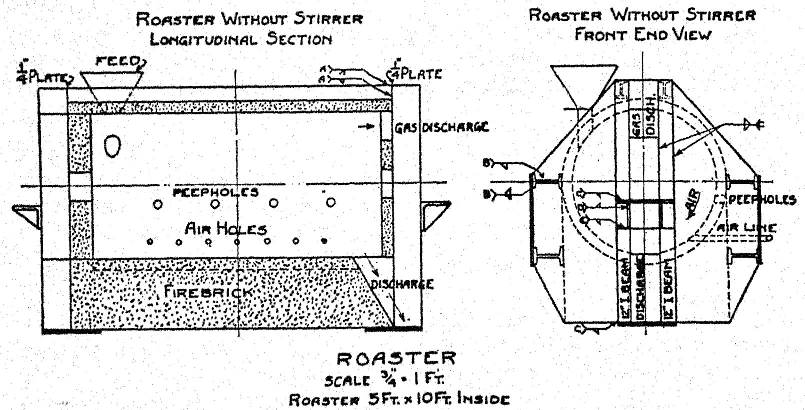


Fig. 1. Details of arc welded ore roaster less stirrer.

the further fact that during the last year a strong movement has set in, in favor of discarding old methods of metallurgy and substituting processes which depend on roasters, would reinforce the conclusion that one billion dollars per annum will shortly be realized as roaster service to industry.

In any event, we cannot escape the conclusion that roasters are fundamentally important to industry, and probably are more important than any other one metallurgical machine.

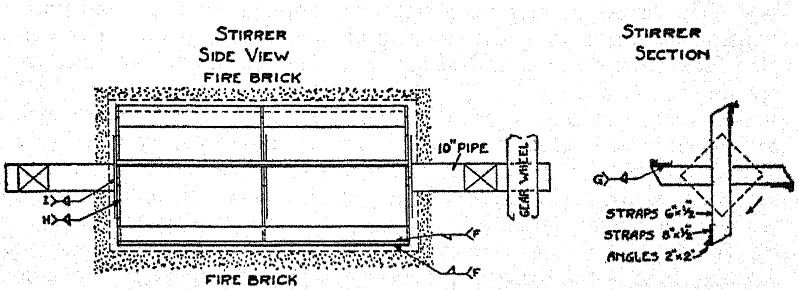
It is on this premise that so much time has been expended to develop a roaster with the highest possible efficiency.

It is felt that the Type D roaster set forth in this paper is the best roaster of the present time in the line of progress. With which preliminary, we next turn to a more minute consideration of the Type D roaster and its construction.

The data for the amounts and money values on the preceding pages was taken mostly from Stoughton and Butts "Metallurgy," "The World Almanac" and from the Bureau of Mines.

The Type D Roaster.—By referring to Figs. 1, 2 and 3, will be seen a sketch of the roaster shell and stirrer, (Fig. 2).

These are plans for a roaster to handle 25 tons per day of a pyritic, gold-bearing ore. While some of the smaller details are governed by this type of ore, the general lines of the roaster construction are the same for all ores and products to be handled by the machine.



Roaster
Stirrer Blades ½"×8" Strap, With 2"×2" Angle,
Diameter of Rotation 4'-6", Length 9'-6", Thus
Providing 3" Clearance All Around.

Fig. 2. Details of stirrer.

The roaster consists of a cylindrical shell, lined with firebrick, and a stirrer, revolving clockwise, when viewed from discharge end. The stirrer blades are arranged somewhat like the cutting blades of a lawn mower.

The shell is stationary and the blades revolve, just the opposite of the Type C roasters. The shell remaining fixed, enables us to insert pipes or openings down the length of the roaster so as to inject fuel or air, or both, into the roaster at any point desired. In this way we can control the temperature at any point. We can start the ore in at feed end at just barely warm and gradually increase the temperature to a white heat at the discharge end. We can feed in the air in any amount at any point of the roaster. These two features are not to be found in any revolving roaster on the present market.

If desired, hot blast can be used in the roasting. The roasting can be either oxidizing or reducing. Part of the fuel can be fed in with the ore, if desired. Peepholes are also provided as an aid in exact regulation of blast and fuel.

Taking up the drawings in detail, Fig. 1 shows longitudinal section of shell with end view of same. Inside the firebrick lining, the roaster is five feet in diameter and ten feet long. The firebrick lining is 4½ inches thick of first class firebrick, except the feed-end lining is nine inches thick; all the rest of the firebrick is second class. The shell is held together by eight 12-inch, 25 lb. I-beams and two 8-inch, 17.5 lb. I- beams (on top). The two end plates are ¼ inch thick, about 8½ ft. high and about 8 ft. wide. The end plate at feed end is cut on about a 5 ft. diameter circle, to permit insertion and withdrawal of stirrer when desired. A clearance of one inch all around is allowed at this circular cutting, to take up any inequality of heat expansion.

Two-inch pipes are thrust through firebrick at points shown on Fig. 1, for entrance of air, or air and fuel. Three-inch pipes make entrance for peep holes. Clockwise rotation of stirrer blades piles up the ore on the left side of cylinder, hence the ore feed is dropped down from this side. The flames coming from right side impinge upon the ore with a swirling motion causing the entering air and flame to rotate clockwise. The fully roasted ore is pushed out by the blades through the discharge opening.

The entire roaster is built on a foundation of concrete, into which are embedded the base plates, one inch thick and about two feet square. The concrete foundation, and consequently the roaster, will be given such slope as may be suitable for the particular material to be roasted. A ten per cent slope will be quite common for ordinary pyrite gold ore.

The speed of the ore through the roaster is governed by three factors: (a), the slope of the roaster, just described; (b), the speed of revolution of stirrer and blades, which will ordinarily be about one revolution for each two minutes; and (c), the rapidity of the feed.

In general, the slope will be fixed when the roaster is "set"; the speed of revolution of the blades will be at least temporarily fixed when the size gear wheels are determined for the particular ore and roast desired. This leaves the one element of feed to be adjusted by the operator. Such adjustment is easy and will require very little time. This will leave the operator free to attend to the differential adjustment of the air and fuel, with the help of the peepholes.

It will be seen at once that this set-up makes for an easy adjustment of the entire operation, so that maximum capacity can be attained with maximum roast quality, with little difficulty, even in the hands of a comparatively inexperienced operator.

Stirrer and Blades.—The secret of the success of the design is in the stirrer and blades. A three-inch clearance is given the blades all around, so that their length is 9½ feet and the exterior diameter of rotation is 4½ feet. The four blades are set at 90 degrees apart, and on each, at the "cutting" edge is mounted an angle bar, 2-inch by 2-inch by 5/16-inch, having a weight of about 4 lbs. per foot. The blades are ½-inch by 8 inches. The blades rest on ½-inch by 6-inch straps, about 4½ feet long, as shown in Fig. 2.

The ½-inch by 6-inch straps are welded onto one-inch blocks of steel at each end, and the reinforcing block in the center is ¼-inch steel instead of one inch. These blocks are each about two feet square. Into each end of these blocks are welded heavy ten-inch pipe, to act as bearing shafting. The shafting thus formed is supported on bearings resting on brackets from the I-beams, as shown in Figs. 1 and 3.

The entire weight of the stirrer, including shafting, etc. but excluding gear wheel, is 1610 pounds.

This compares with about 25,000 pounds for equivalent Type C moving cylinder, steel and riveted, or with 35,000 pounds cast iron. The above weights of course including the firebrick lining, which must be supported and turned over in the Type C roaster.

Before making further comparisons let us calculate the cost of manufacturing the Type D roaster.

COST OF THE TYPE D ROASTER

Welding.—On the three drawing sheets the welding is indicated by the method of symbolizing set forth on pages 36 and following, "Procedure Handbook of Arc Welding Design and Practice," Fifth Edition, 1938.

The welding costs are calculated from the instructions in said handbook for shielded arc, manual welding, found on pages 123 to 173.

The costs of labor, current, electrode, etc. are taken at retail costs in a small machine shop in Denver, Colorado,—on the theory that many of the Type D roasters, especially of the first ones made, will have to be welded and assembled thus. Therefore we are taking the cost of electric current at 3c per kilowatt-hour, labor at $1.50 per hour, cost of 3/8-inch electrode at 21c per pound. The stirrer, except pipe shaft, is made of special heat resistance alloy, being steel with 6% Chromium, and .5% Molybdenum. The special electrode for welding this alloy is taken at 50c per pound, and also taken as being the equivalent of 3/8 inch electrode with shielded arc, although that is not the form specified on those pages, but is taken as equivalent thereto as far as cost is concerned.

Cost of I-beams is taken at 4c per pound, Denver, and sheet metal and other forms 4.5c per pound. The Iron-Chromium-Molybdenum alloy is taken at 30c per pound, Denver.

Both welding costs and other costs of the roaster are purposely kept high, so as to make the cost estimates conservative and safe.

COST DATA

Total Welding for Shell:

Joining 2 top I-beams to 1/4-inch end plates, both ends............2 ft. bevel weld, 8 ft. fillet weld.

Joining 4 horizontal I-beams to 1/4-inch end plate at both ends and to each other............26 ft. fillet weld.

Joining 4 vertical I-beams............2 ft. bevel weld, 80 ft. fillet weld.

Reinforcing 2 bearing brackets and 2 double bolt brackets, (Fig. 3)............ 17 ft. fillet weld.

Welding edge, top and bottom of 2 bolt brackets, (Fig. 3)............5 ft. bevel weld, 4 ft. fillet weld.

Total welding—9 ft. bevel weld, @ speed 10 ft. per hr. electrode 1 lb. per ft.
135 ft. fillet weld, speed 20 ft. per hr. electrode .5 lb. per ft.

Welding:

Labor 12 hours (includes preparation and interruptions) @ $1.50 per hour	$ 18.00
Power @ 3¢ kw hr. 10 hrs. (taken equivalent to 250 volt, 200 amp. @ 50%, 100 kw hr.) 100 k w times 10 hrs.	30.00
Electrode 80 lbs. @ 21¢ (retail Denver)	17.00
Miscellaneous	3.00
Total	$ 68.00

Other Costs:
4 I-beams, 12" 25 lbs., 8½ ft. long, 850 lbs.
4 I-beams, 12" 25 lbs., 12 ft. long, 1200 lbs.
2 I-beams, 8" 17½ lbs., 12 ft. long, 420 lbs.

Total I-beams, 2500 lbs. @ 4¢ lbs. is		$100.00
Two end plates ¼ inch thick 8' x 8½', 1350 lbs.		
6 straps ½" x 6", 3¼', 192 lbs.		
6 brackets 12" x 12" x ½", 2 ft., 480 lbs.		
2 foundation plates, 2' x 2' x 1", 160 lbs.		
2200 lbs. @ 4½¢ lb.		$100.00
Forward: I-beams	$100.00	
Sheets, etc.	$100.00	$200.00
Firebrick:		
1200 first class @ $70.00 thousand	$ 84.00	
1200 second class @ $50.00 thousand	60.00	
Mortar, etc.	10.00	154.00
(Above includes allowance for breakage, etc.).		
Labor other than welding		60.00
Feed funnel, pipes, bolts, and miscellaneous		80.00
Total		$494.00
Welding		68.00
Cost of Shell		**$562.00**

Welding for Stirrer (and Blades):
Joining angles to blades............76 ft. of fillet weld.
Joining 4 blades to straps............16 ft. of fillet weld.
Joining straps to two 1-inch end plates and middle reinforcing plate............ 30 ft. of fillet weld.
Total, 122 ft. of ordinary fillet weld, 20 ft. per hr. electrode .5 lb. per ft. Total, 6 hrs. and 61 lbs. electrode.
Welding 10-inch pipe to plate at each end to make shafting............6 ft. special fillet weld, 1 hr., 9 lbs. electrode.
Total of entire stirrer, 7 hrs., 70 lbs. of electrode.

Labor, 7 hrs. @ $1.50 per hr.	$ 10.50
Power	21.00
Electrode (special) 9 lbs., 61 lbs., @ 50¢	35.00
Miscellaneous	5.00
Total, Welding	$ 71.50
Materials:	
Pipe (shaft) 320 lbs. @ 8 ft. @ $3.00 ft.	$ 24.00
End plates, 320 lbs. @ 30¢ (special)	96.00
Midplate, 40 lbs. @ 30¢	12.00
Straps, 240 lbs. @ 30¢	72.00
Blades, 517 lbs. @ 30¢	155.00
Angles, 152 lbs. @ 30¢	46.00
Collar, etc., 20 lbs. @ 30¢	6.00
Total	$411.00

Cost of Stirrer:		
Welding	$ 71.50	
Materials	411.00	
Miscellaneous	40.00	$522.50
Shell	**$562.00**	
Stirrer	**522.50**	
Total cost of Roaster		**$1084.50**

This would warrant a retail price of $2200.00.

The above costs have been figured for a small machine shop, high power cost, etc. On the other hand, if we can manufacture in quantity, the costs can be lowered materially: for example, power, in quantity, in Denver, can be had for 6/10c k.w.hr. (off-peak loads) to 1.3c per hour. Sheet metal and I-beams in quantity can be bought at 30% to 50% prices lower than that figured above. Labor, in continuity, can be lessened to around $1. per hour instead of $1.50 per hour.

Making these and like deductions for quantity production, including electrode cost 10c pound usual and 15c pound special, we will find that the total cost of the roaster, in quantity production, at Denver, Colorado, will run about $650. and the selling price should be about $1,000.

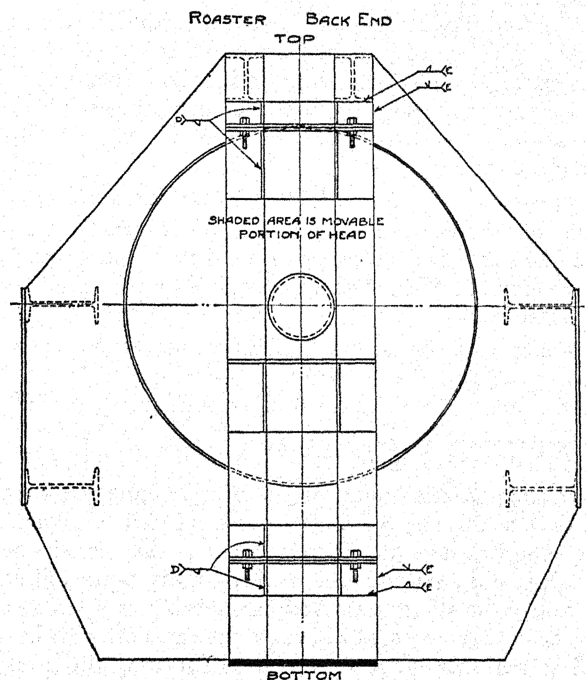


Fig. 3. Details, rear end, arc welded ore roaster.

Cost Comparison, Type D Roaster by Welding vs. Riveting, and Bolts.—On account of heavier sections, plus corrosion at the roasting temperatures against the stirrer, it is not feasible to make the stirrer of riveted construction at all. But for purposes of theoretical comparison, let us assume that such a stirrer, (riveted), could be used and let us calculate the comparative costs of the riveted structure against the welded one.

Beginning with stirrer: the 2-inch angles would have to be riveted to stirrer blades throughout their length, adding to the weight of each of the four blade arms, also depleting the strength of the blades, and angles, to the extent of the holes punched through for rivets.

The straps would have to be riveted or bolted to the end plates with of two extra angles at each of the twelve junction points, adding to the weight again and cutting down the strength of both blades and straps due to rivet holes, to say nothing of added weight and difficulty from the rivet addition.

The straps would have to be riveted or bolted to the end plates with the help of more angles, rivets, etc., with the addition of weight and rivet hole loss of strength.

The joining of the pipe shafting to the end plates would be most difficult. Probably the only feasible way out would be to put a flange on the pipe, then bolt that flange (riveting is out of the question at that point), to the headplate. The headplate, flange and bolts being separate elements, would be subjected to very unequal expansion due to the heat of the roaster. This would put the bolts into three kinds of stress—torsion, falling entirely on the bolts, shear and tension from great difference in expansion between the inside and outside of the roaster and bending, for the bolts would have to support the "beam" over the span of the length of the roaster.

The breakage and wear on the bolts would be insuperable.

How different the situation with welding! The expansion is practically the same, the steel being all welded into one continuous piece. There are no rivets to corrode off in the heat, no spaces for the chemically active, hot ore to crawl into.

Figuring increased size at the general points needed to offset the extra weight of angles, rivets, etc., and make up for loss of strength from rivet holes and bolts we calculate the cost of the stirrer, (figured on wages, power, etc., same as for welding), at $633. by the riveting route, as against $522.50 for welding.

When we come to designing the shell for riveting work, we are at once faced with a difficulty arising from the inherent weakness of rivet work in high temperature atmosphere. Owing to the necessity of numerous replacements and repairs on the stirrer, arrangements will have to be made to take out the stirrer on occasion, probably every few weeks, to repair same or replace parts corroded by the chemical plus heat action. Also it will be necessary to get at the bolts fastening the headplates to pipe shafting, the bolts, or rather the nuts on them, must be accessible from outside. This will mean a complete and very disadvantageous redesign of both feed and discharge ends of the roaster.

The frequent removals of stirrer will also necessitate carrying of the 1/4 inch shell around the sides of the roaster, whereas, in the welded design, these can be left open as shown.

The welded stirrer should not need repair and removal for that purpose oftener than once a year. On that account the shell needs only to be open at one end—the feed end.

Without burdening you with detail, the writer has calculated, going through item by item of redesign, that the roaster shell adapted to riveting design would cost about $768 as against the $562 for welding design.

Recapitulating: the cost of roaster adapted for rivet construction would be $1400, (theoretically, for such construction is really not feasible), as against $1084.50 by welded construction.

Practical Comparison Riveting vs. Welding.—The foregoing comparison is not the real comparison between riveting construction and welding because the riveting method of fabrication is impossible for the Type D roaster. Why? Mostly because the cost of replacing and repairing the stirrer of rivet construction would be so high that a roaster so constructed could not possibly compete on a basis of cost per ton with any of the other types of roasters, to say nothing of the welded construction of Type D.

Except in some very unusual cases, it was found that in Type A roasters the great source of annoyance and expense was the rabbles. Even after adjustment, and with luck, the rabbles would last from one to four months, when they would have to be entirely renewed. From two to eight cents per ton of ore roasted were the best records they could obtain as the cost of rabble repair and renewal. This was an ordinary plain rabble, with no bending or torsion stresses to sustain, just mere attrition.

An important fact that does not seem to have escaped into the literature, but has come forcibly to the observation of many engineers, is that the wear is greatest at rivet and bolt holes and at points where the "raw" metal was exposed by some seams or cracks or roughened edges driven into the ore.

As a comparison in this regard, the welded metal presents to the scouring ore and heat a smooth, unbroken surface, while the riveted pieces expose to the corrosive and heat action a whole series of raw openings for rivets, bolts and what not, and to make the matter infinitely worse, in the case of the Type D roaster, the riveted blades, etc., would have these openings accentuated by the alternating tension and compression due to the bending moment as the stirrer revolves.

Although there are no definite figures found by actual experience as to rivet construction wear, (none of the Type D roasters having yet been built), we could hardly expect a cost of less than 25¢ per ton for the one item of stirrer repairs. Inasmuch as the total cost of roasting, including labor, fuel, power, etc., must be kept down to 25¢ per ton, it is seen at a glance why the riveting type of construction, with a stirrer repair bill of 25¢ per ton of ore, is definitely "out."

Owing to the very great difficulty with rabbles and rabble repairs, Type A roasters have been largely abandoned. Type B is still too expensive for the ordinary case. That leaves the competition between Type C, (revolving, heavy cylinders), and Type D (revolving stirrer, welded). Even with the reduction in price that might be afforded by substituting welding for rivet work on Type C, still Type D is far superior.

The comparison can best be seen by using the market prices of various roasters. The writer has on on his desk the following prices, from dealers, on various types of roasters for 25 tons per day. To this, he is adding the selling price of Type D roaster, both as made by small machine shop and for better facilities. All prices at Denver, Colorado.

Nicholson, Type A	$ 8,000.00
Herreschoff, Type B	10,000.00
Cast Iron, Type C, second hand	6,000.00
Steel riveted, Type C, rebuilt	5,000.00
Muckle Roaster, Type C, welded	3,500.00
Hatch Electric, Type C	10,000.00
Type D, this paper, (small machine shop)	2,200.00
Type D, this paper, (better facilities)	1,000.00

The first six roasters will perform in most localities at a cost of 25¢ to 50¢ per ton of ore. The Type D will roast ore for about 25¢ or a little less per ton under like situations. The great advantage, however, of the Type D, aside from lower initial cost, is the better heat control enabling a more definite and thorough roast, largely due to the insertion of pipes and peepholes in the shell.

Type D is only possible through welding: therefore to welding must go the credit for both the saving in first cost of roaster and for its better performance when in operation.

SECTION X

JIGS AND FIXTURES

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SECTION X
JIGS AND FIXTURES

Chapter I—Development of a Welding Fixture

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The successful application of arc welding as a method of fabrication requires a complete study of all the operations concerned. It is not enough to substitute welding for some other method. This means that holding the parts in position and the effects of the welding on the material must be taken into consideration as well as the possibility of improvement in the economy and appearance of the finished product.

It is the purpose of this discussion to describe the development of a special welding fixture, and in doing so to cover all the steps in the development so that the breadth of this or any similar problem will be more apparent to the reader.

In order that the whole subject may be more clearly understood, we include a full description of the product to be welded, together with a brief history of its development up to the point where increased demand necessitated a radical change in the method of manufacture. Since the material to be fabricated is a high-carbon steel, which introduces a serious metallurgical problem, micro-analyses were made by a leading laboratory. Excerpts from the laboratory's report have also been included where it will help to clarify the discussion.

The monorail systems manufactured by this company utilize a specially rolled high-carbon steel section for the track. Its shape has been developed to give raised wearing surfaces which will resist peening under the action of the trolley wheels, and to facilitate suspension by the use of clamps and hanger rods. Fig. 1 shows a typical method of suspension. Attention is called to the analysis of the rail steel.

When this rail is used for trolleys with heavy loads, the hanger rods are installed on 3′—0″ centers. This close spacing obviously requires a continuous ceiling construction of ample capacity such as is used in reinforced concrete buildings, or, in the case of steel buildings, the providing of superstructure to give the proper suspension points.

As the use of this type of handling equipment became more generally accepted, it was necessary to provide a track which could be used in longer free spans because the superstructure was a large expense item in the cost of installation. Such a track was developed. It had sufficient beam strength to permit spans of 20 and 30 feet and retained the original rail section so far as the wearing surface was concerned. This last point was most important if the manufacturing standards of trolley clearances were to be retained.

The rail section, due to its special close tolerances and special analysis is relatively expensive. The raised wearing strip makes it a difficult section to roll. It was found that the expense of rolling a heavy

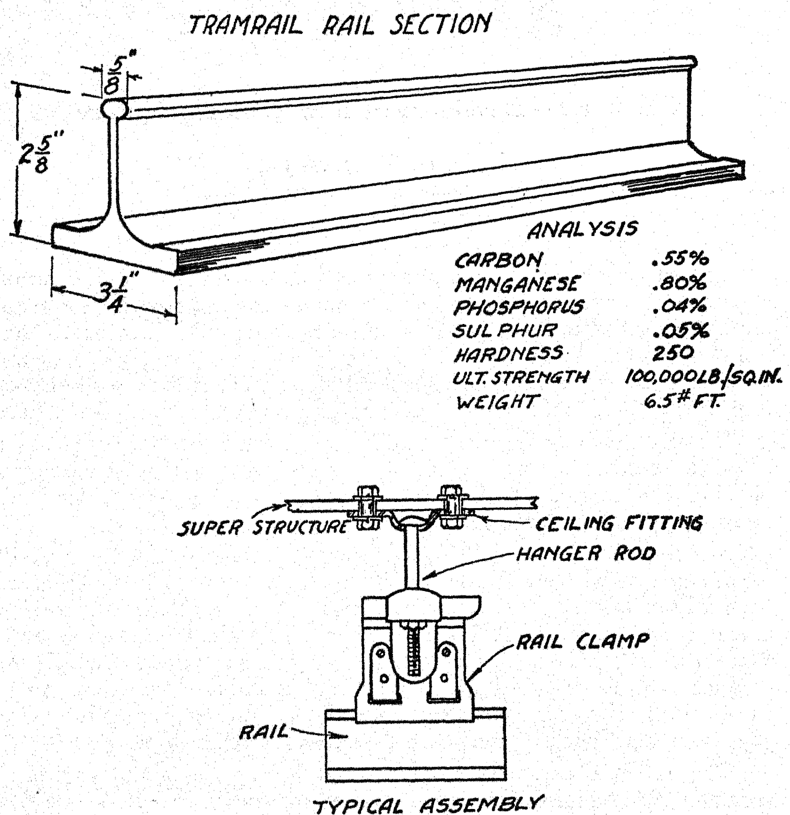


Fig. 1. Typical method of suspension.

I-Beam section of the same material and retaining the shape of the rail at the bottom flange would give prohibitive costs. The only alternative which presented itself was the development of a beam section which would retain the rail as the bottom flange and use ordinary rolled structural steel for the top flange.

Several tentative sizes of beams were considered, but one having a depth of 10″ was the first one to be made. This is the only size we will consider in this discussion, although an 8″ and a 12″ beam are now in production.

Even though lower priced material was being substituted, in part, for the special high-carbon steel, the cost margin was so small that every economy had to be employed. To make up a 10″ beam a 7 5/16″ tee had to be used as the upper part. The strength calculations, as well as other design considerations, called for a top flange width of approximately 6 1/4″. These dimensions did not correspond to any standard rolled tee, so it was necessary to split an I-Beam. The pattern was worked out so that two 7 5/16″ tees are obtained simultaneously from

a 12″ I-Beam, giving a maximum depth to the finished product with the minimum of material.

The only two practical methods of joining the two parts of the beam together were riveting and welding. It is estimated that the direct labor cost for locating, punching or drilling, and riveting the beam would be at least $.10 per foot. Although little or not cost data was available at the time of this development, it was obvious that welding was going to cost much less. As between electric and gas welding, the former was selected because it would probably cost at least 30% less.

Since the weld was to be longitudinal, it was not necessary that it be continuous. The shape worked out in the splitting pattern was quite suitable. It was only necessary to provide ¼″ weld thickness at each 2¾″ joint, or ⅛″ on each side, to give the joint an ultimate strength in excess of 40,000 lbs. Since the trolley wheel loads are limited to a static value of 3,000 lbs. per pair, this left an ample factor of safety.

Welding thus presented the best solution to the connection problem, with one exception. Trouble started at once from attempting to weld the high carbon steel. Cracks occurred frequently in the welds or near them. It was observed that the cracks invariably occurred in the rail, and not in the upper section. It was soon determined that the excessive localized heating of the high-carbon steel was causing the cracks, and that some procedure must be developed to eliminate the effect. There was limited general knowledge about the welding of air-hardening steels, but it was thought that if the welds could be built up gradually, welding each joint a little bit at a time, it would avoid the setting up of critical heating conditions. Half of one side of each joint would be welded throughout the beam, and then half the joint on the opposite side. This process was continued until all the welds were completed.

The early studies did not reveal whether preheating or stress-relieving was the proper treatment of the welds, but both effects were probably present in the established procedure. The first weld would preheat the joint for the later welds, and the later welds would tend to stress-relieve the first ones. In all events, the results were excellent, and no more cracks or failures were reported.

This method of making the beam was used from 1928 until early 1937. Each section of beam was made to exact length to suit the purchaser's building requirements, no stock being kept on hand. As the demand for this type of track approached 100,000 feet per year, it became apparent that a faster and more economical method of making the beams was necessary, and that a stock had to be carried to facilitate quick delivery and smooth out production curves.

Preliminary studies of the manufacturing problem showed that some continuous method of welding would be the most economical one. Considerable time could be saved if some fixture were provided so that each weld could be made in one operation instead of four. Further studies indicated that the most suitable fixture would be one that automatically located the two parts of the beam and moved them at a continuous rate past the two operators located on each side of the beam.

Earlier experiences with the welding of the beam showed that the design of the fixture was only half the problem. The metallurgy of the weld was even more serious if the welds were to be made continuously and not crack. The original "step-by-step" method of welding each joint was automatically eliminated by any continuous procedure that might be adopted. It was out of the question to change the analysis, so some method of controlling the air-hardening characteristics had to be worked out. Both preheating and stress-relieving were considered and a number of test specimens employing these treatments were made up. It was recognized that the low temperature preheat was far more economical to achieve in practice than 1100-degree stress-relief, but it was left to a microscopic analysis of typical sections for a decision.

Specimens were prepared in a manner which approximated the proposed practical procedure and were submitted to the laboratory for impartial analysis. Some of the pieces were welded at room temperature, and half of these stress-relieved by heating to 1100 degrees, while other pieces were preheated to temperatures varying from 200 to 325 degrees before they were welded. We quote in part from the laboratory's report:

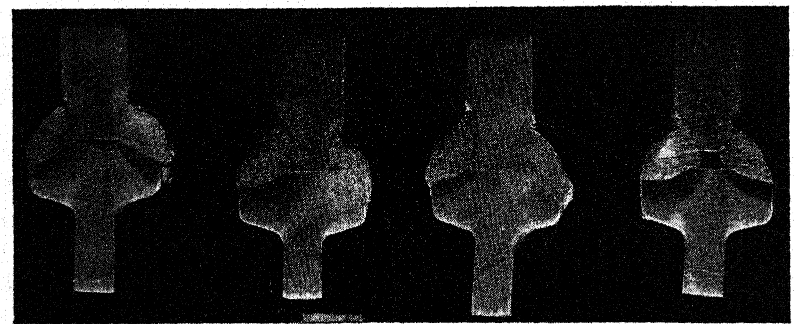


Fig. 2. Photomacrographs of welded sections showing change in structure of material under influence of preheating. Left—room temperature; next, 200° F.; third, 300° F.; right, stress relieved. Lower piece high carbon steel. Righthand weld made first in each case.

"In Fig. 2 is shown the macro-structure of four representative sections . . . etched for the purpose of revealing the outlines of the welds and the extent to which the structure of the base metal has been affected by the heating. The section on the left is of the specimen without any preheating. The next section is through the weld made when the parts were preheated to a temperature of 200°F. The third section was preheated to 300° F. and the fourth section was not preheated before welding but was subjected to the stress-relief treatment. . . . The weld metal appears to be well joined to the two base metals. An objectionable feature of this weld is the undercutting of the base metal at the upper edges of the weld. . . . (NOTE:—This undercutting was completely elimi-

nated in actual practice by the selection of the electrode and adjustment of the current.—Author). . . . It may be noticed that in all four sections the depth to which the high carbon steel was affected was less on the right hand side than the left. This is because the fillet weld on the right side was made first in each instance. The heat produced by the first bead permitted the heating by the second bead to penetrate further and to heat a greater depth of metal above the critical temperature. It may be noticed that in the specimen on the left, for which no preheating was used, that the affected areas do not intersect.

"The next section to the right which was preheated to 200° F. has a much greater depth of heat effect on each side, and the welding of the second side caused a recrystallation of the grains to a distance that intersected most of the metal affected when the first bead of metal was applied. This same condition was found in the third section from the left in which the preheating temperature was 300° F. and the penetration appears to have been somewhat greater in this case. Again in the stress-relieved specimen there was no intersection of the heat affected areas. This is as should have been expected because the materials were not preheated before welding."

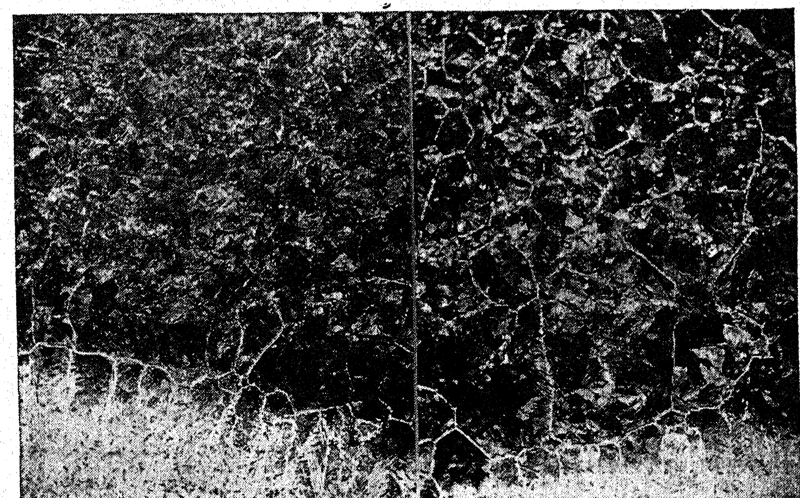


Fig. 3. Photomicrographs showing effects of preheating on the high carbon steel. Left—not preheated; right—preheated. Light section is weld.

Fig. 3 shows two photomicrographs of the welded specimens. We quote the laboratory comment on these photos:

"Negative 2280-x100, (right, Fig. 3). This is a photomicrograph of the junction at the second bead on the specimen that was preheated to 200° F. The weld metal appears to be similar to that on Negative 2278, (left, Fig. 3), except in this case the grains are somewhat larger.

"The high carbon steel grains adjoining the junction and throughout the area covered by the photomicrograph are larger than on Negative 2278, (left, Fig. 3). The ferrite envelope around these grains is thicker than in Negative 2278, (left, Fig. 3). This means that these grains near the junction were heated to a somewhat higher temperature and remained at the high temperature for a longer time, and the rate of cooling was slower, thus giving more time for the separation of the ferrite."

Fig. 4. Photomicrograph of first bead welded. Note spheroidization indicating effect of heating high carbon steel above critical temperature.

Fig. 4 is the laboratory Negative 2279-x100. We quote the comment:

"In this photomicrograph the structure at the weld section of the bead on the first side welded of the specimen preheated to 200° F. is shown. There appears to be a slight recrystallization of the weld metal at the bottom of the print, and much of the high carbon steel in the heat affected zone has been recrystallized because it has been heated at and slightly above the critical temperature by the welding of the second bead. There is evidence of the starting of spheroidization in this structure. In the specimens heated to

higher preheat temperatures this recrystallization was more complete. . . . Very little difference could be observed between the structures on the specimens welded without preheating and in the one also welded without preheating, but subsequently heated to a temperature of 1100° F."

These microscopic studies explained, in part, our experience with the progressive method of welding the archbeam and the conclusions expressed by the laboratory confirmed out tentative decision to employ preheating. We quote:

"*Conclusion.* In this investigation of arc welded high carbon steel, the preheating of the steel before welding was found to be a decided benefit because it was hardened to an appreciably less degree than the steel not preheated before welding. Since there was a marked difference in the depth to which the steel was heated to a temperature that would alter the structure, the temperature gradient was necessarily much less steep and the stresses due to the thermal treatment were therefore less concentrated in the specimens that were preheated."

On the basis of these studies, the decision was made to preheat the pieces of the beam to 350° F. before welding. The second step in the development of the process concerned the equipment to per-

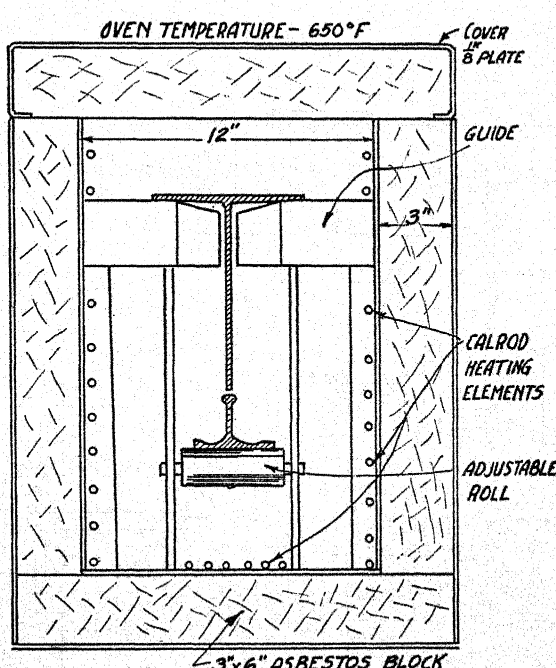


Fig. 5. General arrangement of preheat oven.

form the preheating. The following methods were considered and thoroughly investigated:

1. Gas-fired Muffle
2. Oil-fired Muffle
3. High Frequency Induction
4. Oxy-acetylene Flame
5. Electrical Resistance Muffle

From the standpoint of economy, control and cleanliness the last mentioned heating unit was selected and built. It was constructed generally as shown in Fig. 5. Assuming a production rate of 60 feet of beam per hour, the heat input to the beam would be at the rate of 12 kilowatts per hour and the oven losses about 6 kilowatts per hour. At \$.01 per KW hour, the cost of heating the beam would be approximately \$.0033 per foot which is negligible in view of the increased output.

A study of the other facilities of the department and the probable production demands indicated that a rate of fabrication of 75 feet per hour would be satisfactory. At this rate and an oven temperature of 700° F. it was estimated that the beam could be brought up to the desired temperature in about 10 minutes. The oven was made 12 feet

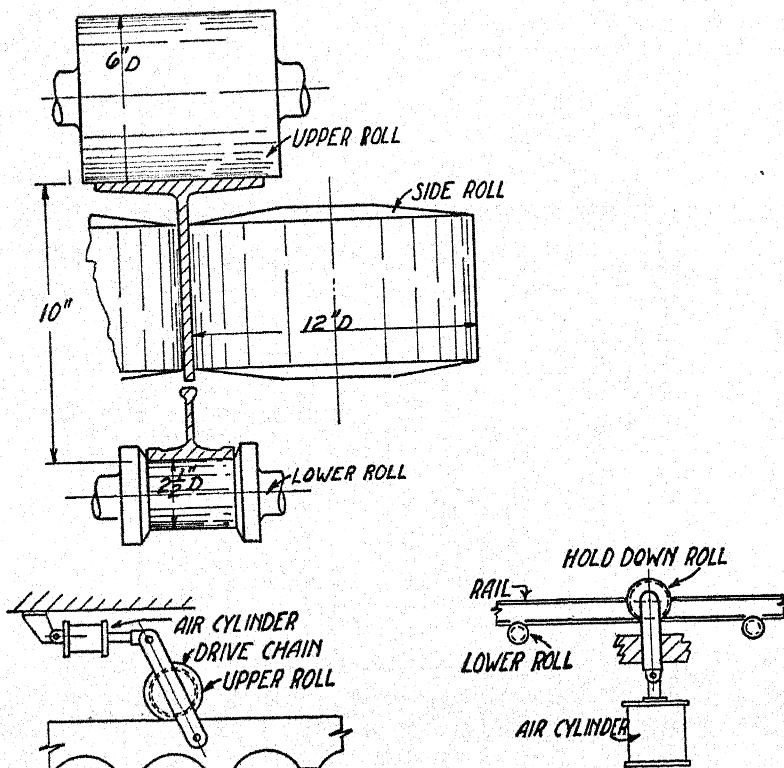


Fig. 6. Arrangement of guide rolls.

long and lined with resistance heating elements having a total capacity of 60 KW. These were installed in two banks, each one having separate thermostatic control. Heavier beams than the 10″ size are also made in this fixture so it was decided to install ample capacity of heating elements at the outset. Furthermore, failure of one or more elements would not disrupt production due to the large spare capacity. It is interesting to note that, after adjustment, 650° F. was found to be the proper oven temperature and that is the setting now used.

The third step in the development was the construction of the fixture to hold the parts in proper alignment for welding. It divided itself into two parts, the first being to locate the pieces and the second to provide continuous movement through the preheat oven and past the welder.

Reference to Fig. 6 shows the arrangement of the guide rolls which locate the pieces. For interchangeability and standardization of the product it is necessary to hold the depth of the beam to exactly 10″. This is accomplished by the vertical distance between the upper and the lower rolls. Since the rail is rolled specially to close tolerances for web centricity, grooving the lower rolls served to locate the rail sideways. The top section is subject to standard rolling tolerances so side rolls were proved necessary to hold the two webs concentric.

To hold the top and bottom pieces in solid contact with their respective rolls, air cylinders actuating hold-down rollers are used. The confining pressure developed by these cylinder mechanisms is sufficiently great to permit driving through the roll designated at top of Fig. 6 as "upper roll". In practice, the two parts of the beam are tack-welded at one joint just before they enter the oven so that the top section only needs to be driven, the rail being "towed" along with it at exactly the same speed. This eliminated the necessity for a synchronized drive for the rail.

The drive of the top rolls is accomplished by a 1 HP induction motor through a speed reducer. The reducer is connected to the three top rolls by sprockets and chains so that a constant surface speed of 15 inches per minute is maintained, which gives the required production speed of 75 feet per hour.

The rolls are so placed that room is provided between them for the welders, one on each side of the beam. The first weld is made by the operator seated between the first and second rolls and the weld on the opposite side is made by the operator located at the third roll just where the beam emerges from the fixture.

Since the first 15 feet of the beam must pass through the oven before any welding takes place, the same essential locating and driving elements were installed at the entrance to the oven. A separate drive operates this first set of rolls, but there is sufficient slip in the motors so that the beam can be driven from both sources simultaneously without difficulty. It is not necessary to disconnect the first drive when the beam is engaged by the second. Each drive motor is equipped with a reversing switch within easy reach of the operators, and each unit of the locating rolls has its own air valve to operate the cylinders. This makes it possible to stop the travel instantly to correct any faulty alignment or to go over a weld a second time if necessary.

The accompanying photographs, Figs. 7 and 8, show the general arrangement of the drive, the rolls and the adjacent roller conveyor which supports the beams before and after welding. The small gantry crane in Fig. 7 is used to put in and take out the beams and to service the equipment.

The use of this fixture has made it possible for two welders to produce ten 40-foot stock beams per day, as compared with the former

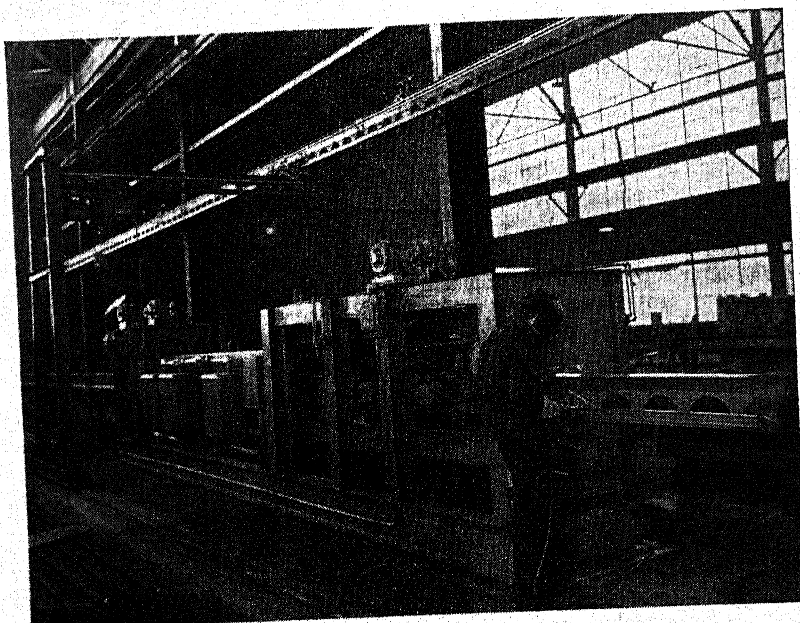


Fig. 7. General arrangement of drive, rolls and adjacent roller conveyor which supports beams before and after welding.

production of 120 feet per man per day. If a helper is provided to feed the beams into the oven and to take away the finished ones, this rate can be stepped up about 20 per cent, but the costs are not improved proportionately. The helper is used only when peak production requirements are encountered.

The straight line production has permitted a new layout of the department. The beams are now stocked in 40-foot lengths so that delivery can be made in three or four days. Formerly it was necessary to cut the top and bottom sections to length, straighten them, and then weld them together. Now the beam is cut as a unit, and much of the straightening is eliminated because the roll stand is strong enough to pull the pieces into line before welding. The product is now carefully controlled and the metallurgy known to a fair exactitude.

The production per square foot of floor space has been materially increased because the progress is controlled and orderly and proceeds with a minimum of waste motion.

It is not possible to present exactly comparable cost figures to substantiate the production savings made by use of the fixture. It is known that, in spite of a wage scale as high as it has ever been, the direct labor cost for storing, splitting, handling and welding the beam is \$.045 per foot. On a pound basis, at 21 pounds per foot of beam, this represents a cost of approximately \$.002 per pound. This is a small fraction, probably about 20%, of what the increase in material cost would be if the beam were to be rolled in one piece.

The period of transition from the old method to the new saw an increase in labor rates of about 25% and the new layout of the department changed the operations and hence the computations of the various expense items. It is known, however, that at a cost of \$5,000 this fixture has increased the man-hour production by 65%, that the power

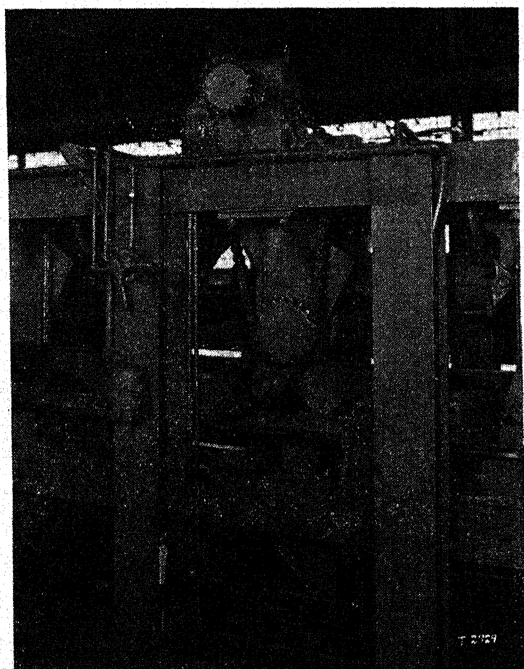


Fig. 8. Close up of drive.

consumption is negligible, and that the control of the quality of the product is greatly improved. These facts are presented as proof of the correctness of the solution to the problem.

In conclusion, attention is called to the fact that the fixture itself was constructed of structural steel shapes arc welded together to give the greatest rigidity. All connections were welded except where adjustment was necessary, or where machined surfaces required bolted assembly. The work was done by regular welders in the plant structural department, in between standard production jobs.

Chapter II—Large Two-Position Index Drill Jig Arc Welded from Rolled Steel

By T. C. MELLON,
General superintendent, Worthington Pump and Machinery Corp., Buffalo, N. Y.

With the introduction of arc welding not so many years ago, a new field of construction was opened to the designer of metal products. The centuries-old tradition of producing all irregular shapes by castings was a necessity until arc welded steel construction was developed. Today, it is generally recognized that this new method represents a worth while saving and therefore is used increasingly in all branches of metal and machine manufacturing. Especially on products which are not reproduced, the elimination of the pattern cost alone is, in many cases, a sufficient saving to permit the economic manufacture of the design.

In this category of non-repetitive work, the manufacturing of production equipment is the most important item. That explains why the first extensive application of electric welded construction was employed in the production of jigs and fixtures. The essential factors for the quick and economic manufacture of jigs and fixtures, namely accuracy, versatility, greater strength and rigidity, flexibility which permits quick changes, refinements and improvements are all inseparable qualifications of electric welded construction. Reduced weight is another advantage especially on larger applications where savings in weight mean savings in productive energy.

An example of a large two position index drill jig arc welded from bar stock, steel tubing and torch cut steel plates into a complete unit is shown in Figs. 1, 2 and 3. The jig is used for the following operations on a 200-pound drop-forged diesel and gas engine connecting rod (See Fig. 4): drill and spot face bolt holes, drill oil hole through entire rod, spot face boss on foot end to correct length from eye end, drill, tap and counterbore for wrist pin bushings lock screw and center both ends for the next operation. The drill bushing plates on top with two or four holes respectively are interchangeable for a two or four bolt connection rod.

The equipment used for the economic fabrication of arc welded jigs and fixtures is a No. 4 automatic cutting machine for torch cutting all intricate shaped parts. The tack and line welding is done with a 300 ampere welding machine, shielded arc welding rod. This machine was transferred from our Massachusetts works to the Buffalo works in 1928 and for the last ten years has given continuous good service on all welding jobs within its ranges.

Out of the battery of six machines available, this machine is liked best by the welders due to its smooth action without splattering and its flexibility which permits welding of thin and fragile sections without

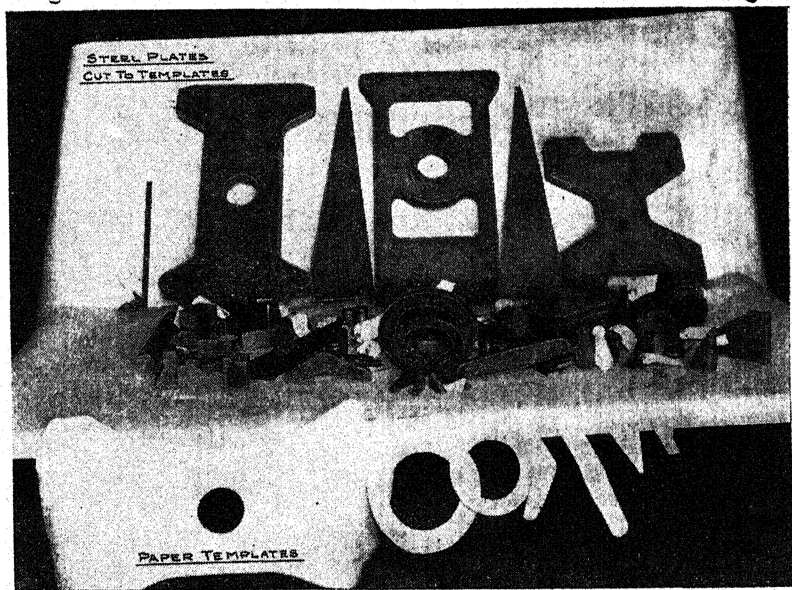


Fig 1. Steel plates for jig cut from templates.

burning as well as the heavy beads necessary on large work. In the processing of welded jigs, all irregular shapes are cut on the flame cutting machine to a template which the draftsman cuts out of old drafting paper. This eliminates all lay-outs by the torch cutting machine operator and since these templates have the stock thickness and all other information on it, neither drawing nor lay-out is required for the shape cutting of the odd parts.

In Fig. 1 the torch cut plates are shown with some of the paper templates used for cutting the required shapes. From here the plates are moved to a setting up bench where all the necessary additional parts from bar stock cut-off room are assembled and electric tack welded in position by a competent welder. After checking all dimensions, the tack welded parts are moved to one of the welding booths where an ordinary welder does all the line welding.

In Fig. 2 all welded parts of the jig are shown after a strain relief heat treatment and sandblasting. It can be noted that the spring-plunger guide block on the lower right hand side is not welded in place. This assembly was for economy's sake completely machined and then welded in place. All the parts are then machined to the dimensions shown on the drawing after which they are assembled into the complete unit. A complete cost analysis is shown on the attached sheet with a comparative estimated cost for patterns and castings. These estimates were prepared by pattern shop and foundry superintendents respectively with many years of experience and are rather conservative since both were interested in getting the job in their respective departments. The actual time for welding and machining was carefully

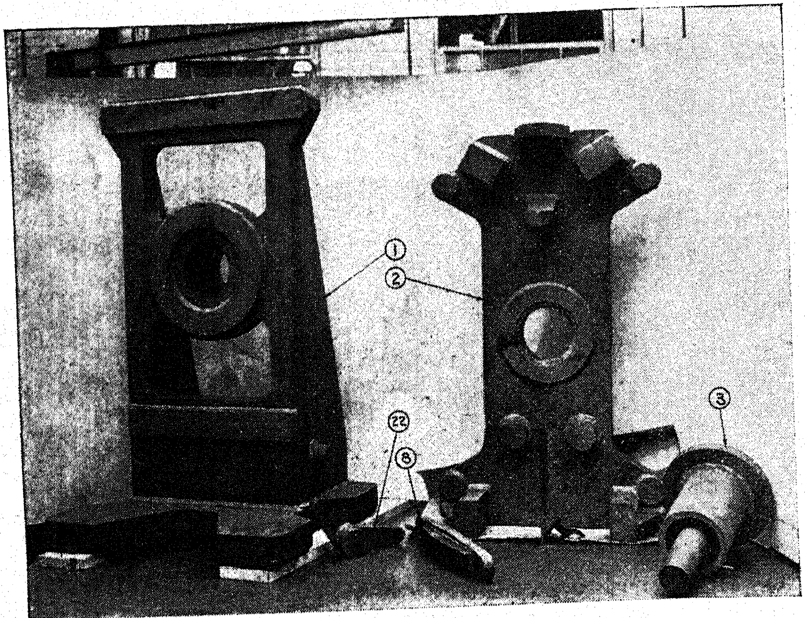


Fig. 2. Arc welded parts of jig after strain relief heat treatment and sandblasting.

recorded and the cost computed by experienced cost clerks. The welding speed of two (2) inches per minute is the standard used in general by time study departments for this kind of welding and the welding machine operator made premium on this set rate. The completed jig was carefully inspected in detail by the tool inspection department and found correct in every respect.

Fig. 3 shows the finished jig and one of the two different connecting rod drop forgings for which the jig was made.

Fig. 4 shows the jig in actual use on a five-foot radial drill with a connecting rod in the fixture and a finished machined rod alongside. For clarification, the photographs are inscribed with numbers for the different parts.

COST ANALYSIS OF DRILL JIG FOR CONNECTING ROD

WELDED STEEL CONSTRUCTION

Torch cut to template	7½ hrs. @	$1.80	equals	$ 13.50
Saw Cut Stock Material	1½ hrs. @	1.50	equals	2.25
Set up and Tack Weld	6 hrs. @	1.80	equals	10.80
Arc Weld complete 978 inches of weld, Welding speed—2 inches per minute equals 489 minutes equals 8¼ hrs. @		1.80	equals	14.67
Material 1648 lbs. at $ .0377 per lb.			equals	62.13
		Total................................		$103.35

CAST IRON CONSTRUCTION

Estimated time for patterns 90 hrs. @ 2.00 equals	180.00		
Estimated Material 80 ft. pine equals	7.50		
Estimated time for molding 17 hrs. @ 1.80 equals	30.60		
Estimated weight of castings 2273 lbs. @ .07 equals	159.11		
Total		377.21	

Saving by Arc Welding without machining cost:
$377.21 — 103.35 equals $273.86 or 72.6%

Cost of Miscellaneous Material	63.84	
Cost of Purchased Material	52.60	
Total Machining and Assembly time 198 hrs. @ $2.00	396.00	
Total		512.44
Total cost of finished jig in fabricated construction and arc welded	512.44	
	103.35	
		615.79
Total cost of finished jig in cast iron construction	512.44	
	377.21	
		899.65

Saving by Arc Welding on Finished Jig
= $899.65 — $615.79 equals $273.86 or 30.8%

The summary of this analysis is an actual saving of $273.86 or 30.8% in cost and a saving in weight of 625 lbs. or 27.4% by arc welding over cast iron construction. In addition to these tangible savings, a number of immeasurable gross savings are realized. The rapid advancements which are made today in every branch of industry require an equally rapid change of production methods and equipment. Rapid obsolescence of products, which is so essential to industrial and social progress must be balanced by a production system equipped to adapt itself to the changes of demand quickly and economically. Electric arc welding has contributed to this by improving the nation's facility for producing.

The possibility to produce from rolled bars, plates and structural shapes complete machines, jigs and fixtures, to strengthen the construction but nevertheless lessen the weight and to use alloy steel only when and where needed are the structural advantages of arc welding. Decreased production cost, a better appearing product with increased accuracy and life, quicker deliveries and the flexible design possibilities restricted only by the ingenuity of the designer, are the inherent economic advantages of electric welded fabrication. Reduced manufacturing costs are a sounder foundation than the mere increase in sales and the saving of 30.8% in cost and 27.4% in weight on the application described in this paper is the average for all other applications. In this case as well as in many others, the saving obtainable with this new method was the deciding factor which justified the making of the jig.

It is a well known fact that production equipment, especially jigs and fixtures are responsible for higher production and lower cost and thereby have reduced the price of countless products to a level attainable by the common people. It is only by replacement of the old with the new and superior methods that modern development can be put into use

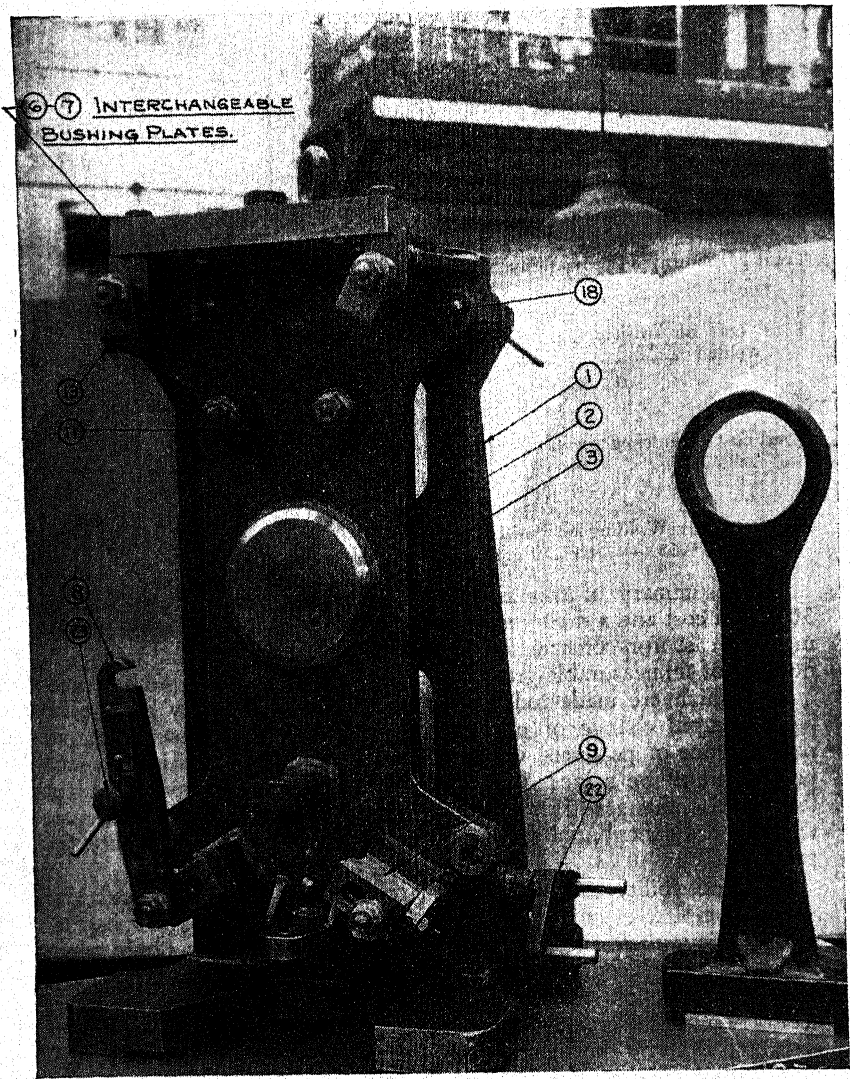


Fig. 3. Finished jig and a connecting rod it is used to drill.

and enjoyed by the public. By incessant striving for new production techniques and processes, new jobs and new sources of income are created.

The tenacity with which man holds to tradition is surprising. Yet progress cannot be stopped by sentiment or tradition. The revolution of production will go on forever with the aim to increase the buying ability of each man. Every application of a new method as the one

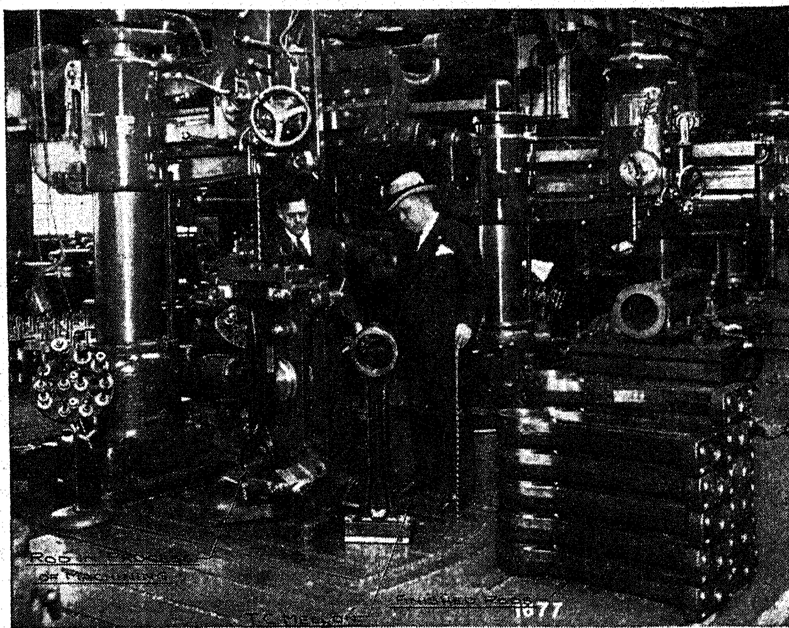


Fig. 4. Arc welded jig in use.

set forth in this paper is a contribution to progress. With the increased use and refinement of the electric welding process and by its virtue, economy and versatility, it will become the foremost method of construction to the benefit of all men.

Chapter III—Redesign of Milling Fixture from Cast Iron to Welded Steel

By A. S. CURRY,
Methods supervisor, Nash Engineering Co., Norwalk, Conn.

The manufacturing company, with which I am connected, manufactures vacuum, compressor, and centrifugal pumps. The selling price of these pumps is based on economical machining cost and tools. Jigs and fixtures, play an important part in setting the selling price. When the tooling cost has been estimated, it is prorated over the number of pumps which the sales department estimates that it can sell in a year. This prorated cost is then added to the selling price, which has to be based on competitive value. Therefore, it becomes necessary for engineers to spread economical dollars where they will show the best results.

My position as methods engineer requires the designing of fixtures with economy of cost both in regard to design and time required to perform the machining operation on the particular part being taken into consideration and in regard to quantities being machined and the quality of work which is required to pass the necessary inspection requirements.

The accompanying application, or improvement, is the redesign of

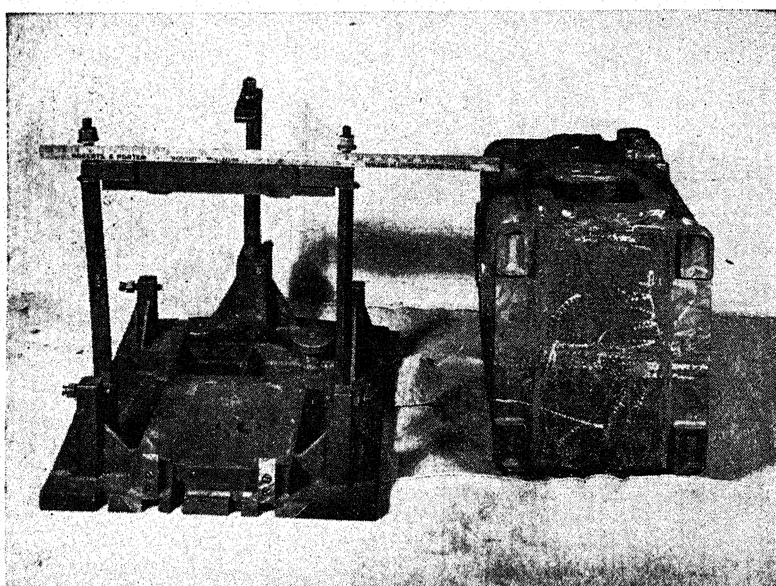


Fig. 1. Cast iron fixture and work.

a specific type of milling fixture from cast iron to arc welded steel construction.

The detailed cost is not estimated but is based on actual cost as compiled from cost records.

First, we will describe in detail the cast iron fixture, its use, and cost including labor and material. Then we will describe in detail the arc welded steel construction, also its use and cost including labor and material. Finally, we will describe the advantages of arc welded steel construction over the cast iron design both in regard to cost and weight.

Cast Iron Milling Fixture.—This fixture was designed for milling the feet of a duplex unit type heating pump tank, with sixteen-gallon capacity, and weighing 417 pounds. Assembled fixture and work are shown on photograph, Fig. 1.

The work is assembled into fixture by double stud strap shown in Fig. 1. Two long bolts or studs are first swung out of position, hinged at the bottom of fixture and rear strap is also swung into back of fixture. The work is placed on fixture and is adjusted into correct location by two adjusting screws in rear of fixture. After the work is mounted in fixture, two long studs are then swung into position, a double strap placed on top of work and then tightened down on work. The rear strap is also swung into position and strapped down. Adjusting screws on sides of fixture are then tightened against work to eliminate any possibility of work shifting when milling cutter is fed into work. The fixture is designed rigid enough to allow cutters to travel 12" a minute. An 8" cutter with 16 inserted high speed steel cutters is used.

The design of this fixture required the making of a wood pattern from which a cast iron casting was made. The over all, or machine space of fixture, is 30½" long, 25¼" wide, and over all height 28" with the studs and clamps in position.

A detailed cost is shown below and is not estimated but is based on actual cost compiled by cost records.

Cost of pattern	15 hrs. @ $2.50 per hr.	$ 37.50
Machining fixture to specifications	47 hrs. @ 2.50 per hr.	117.50
Cast iron casting for base— 356 lbs. @ $ .05½ per lb.		19.58
Material including machined steel, standard screws and nuts		4.58
TOTAL HOURS	62 hrs.	
TOTAL COST, CAST IRON FIXTURE		$179.16

In order to change the above hours into cost I have used an average departmental rate which is based on pattern shop, tool room, and welding department.

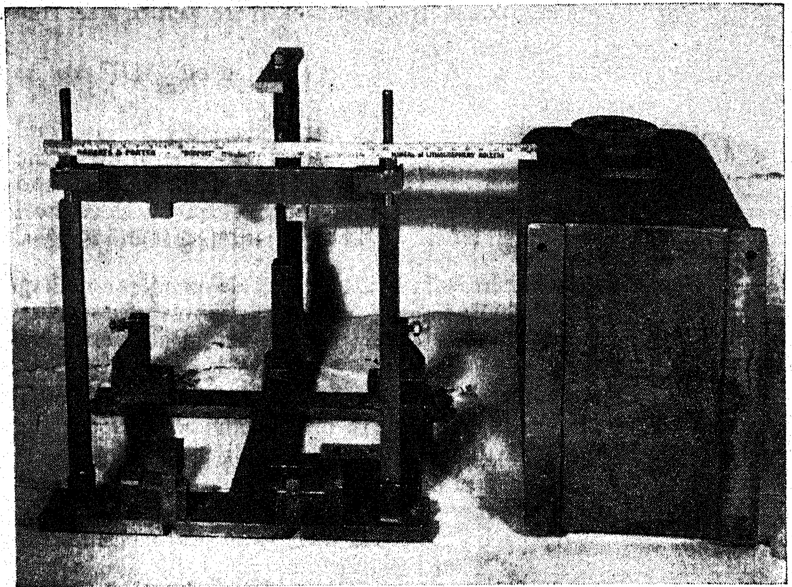


Fig. 2. Arc welded fixture and work.

Arc Welded Fixture.—This fixture was designed for milling a similar product as the cast iron fixture, for the same operation, on the same machine, and was for a single condensation heating pump tank with twenty-gallon capacity and weighing 386 pounds.

Assembled fixture and work are shown in Fig. 2.

The work is also assembled into fixture with the same procedure as the cast iron milling fixture; that is, the double stud strap on top of fixture. Two long bolts or studs are first swung out of position and are hinged at the bottom of fixture. The work is then placed in position on the fixture and it is adjusted into correct location by the adjusting screw jack shown in rear of fixture. After the work is mounted into the fixture, the two long studs are swung into position, a double strap placed on top and then tightened down on work. The rear strap is also swung into position and tightened down. Adjusting screws on side of fixture are then tightened against work to eliminate possibility of work shifting when milling cutter is fed into the work.

This fixture was designed rigid enough to allow cutter to travel at the same speed as cast iron fixture; that is, 12″ a minute. An 8″ cutter with 16 inserted high speed cutters is used the same as on the cast iron fixture.

It was decided to design this fixture of arc welded construction for reduction in cost of tools on this milling operation.

The parts for this fixture were then prepared for welding in the tool room; that is, to correct lengths and any milling or drilling that could be machined more economically before, rather than after, the welding operation.

The over all, or machine space of fixture, is 32″ long and 29″ wide. Over all height is 32¼″ with studs and clamps in position.

A detailed cost is shown below. This is not estimated, but based on actual cost compiled from cost records, which are exactly the same as the cast iron fixture.

Cost of preparing milling and drilling parts before welding	10 hrs.	@ $2.50	$ 25.00
Arc welding fixture	6 hrs.	@ 2.50	15.00
Machining fixture to specifications after welding	21 hrs.	@ 2.50	52.50
Material including machine steel, screws, and nuts			17.89
TOTAL COST, ARC WELDED FIXTURE	37 hrs.		$110.39

In order to change the above hours into cost, I have used the same departmental cost as used on the cast iron fixture.

Arc Welded Construction Versus Cast Iron Construction.—I have described in detail a milling fixture designed for cast iron construction and arc welded construction. This leads to the conclusion that the advantages are all towards the arc welded construction over the cast iron construction. My conclusions are as follows:

1. Milling and drilling of certain parts, which cannot be done on cast iron fixtures, can be more economically machined before welding than after the welding operation.
2. With a cast iron fixture a wood pattern has to be made in order to purchase the casting. After the casting has been made, the wood pattern is of no further use and is practically a loss in comparison with the arc welded construction. In this particular application the pattern amounted to $37.50. Therefore, the design of fixtures should be given careful consideration before designing of cast iron fixtures instead of the economical design of arc welded construction.
3. Actual finished weight of the cast iron fixture is 380 lbs. Actual finished weight of arc welded fixture is 306 lbs. This is a saving in weight of 74 lbs. or 20% less.
4. Total cost of cast iron construction is 62 hrs., or $179.16. Total cost of arc welded construction is 37 hrs., or $110.39. With the arc welded construction there is a saving of 25 hrs. or $68.77, which results in a 40% saving in hours and 38% in cost. This is a very substantial saving in fixture expense and has been based on actual cost from records. This saving is reflected back into the cost and a final reduction in selling price of product.
5. It should also be noted that the cost of material including cast iron base on the cast iron construction fixture is $24.16 and the cost of material in the arc welded construction is $17.89, or a saving of $6.27 on material alone. As stated above, the differ-

ence in finished weight between the cast iron and arc welded construction is 74 lbs. and based at an approximate price of $ .06 per lb., shows $4.44, which is fairly close to the above price of $6.27.

6. Projecting parts on cast iron fixtures can be accidentally broken off in handling. This cannot be done so readily on steel constructed fixtures.
7. Time is a vital factor in making fixtures for rush orders. As described above, there is a 40% saving in time on the arc welded fixture and there is no delay in waiting for wood patterns and castings as on the cast iron fixtures.
8. Cast iron fixtures will show considerable wear and will have to be remachined on the finished faces more often than the steel constructed fixtures.
9. It is often necessary to make alterations to fixtures so that another part can be machined from the same fixture. With the welded construction fixture a part can be removed by heating with a torch and a new part can be added by welding. With the cast iron fixture a section has to be milled off and the new part screwed and doweled to fixture. This involves a considerable amount of time.

Chapter IV—A Welding Fixture for Welded Bed Plates

By A. W. Bjorkman,
Otis Elevator Co., Yonkers, N. Y.

A monograph prepared to stimulate creative thought and interest in the application of welding fixtures in the fabrication of welded products . . . so that still greater benefits may accrue to mankind through arc welding.

Welded Bed Plates.—Designing engineers were quick to recognize the economies in cost and weight that could be effected by the adaptation of a modern design based on the use of standard steel shapes and the electric arc welding process.

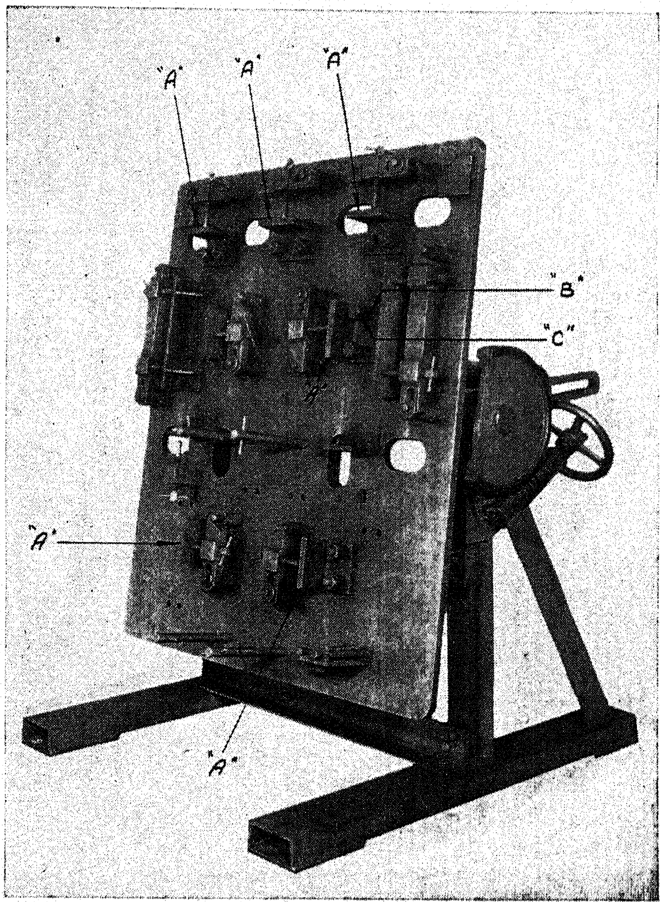


Fig. 1. Complete welding fixture, table tilted.

Welding Fixture.—To build a single welded bed plate presents one problem, but where the required quantity of the same bed plate is large then production methods may be used. Many repetitive operations can be entirely eliminated or reduced to their simplest form.

After a careful analysis of each operation required in the assembly and welding of a complete bed plate, a combination assembling and welding fixture was built. A fixture into which the component parts could be easily placed, simultaneously aligned and clamped without the need for highly skilled labor. The use of this fixture eliminates the

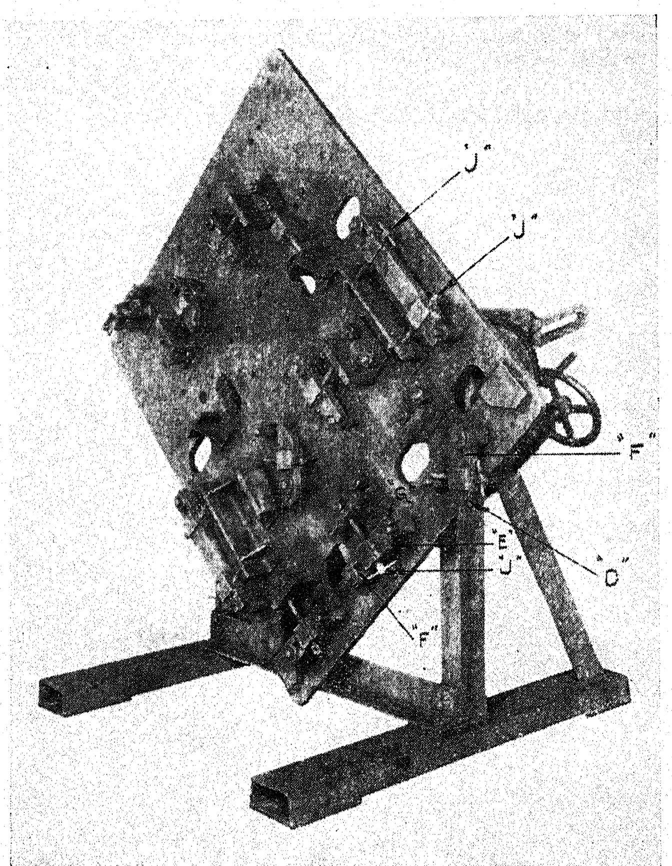


Fig. 2. Quick-acting clamps minimize loading and unloading time.

customary tedious layout, aligning and clamping operations. Quick-acting clamps reduce the time required to release and remove the finished welded bed plate from the fixture.

This combination assembling-and-welding fixture has proven to be both practical and economically sound: practical because it has been

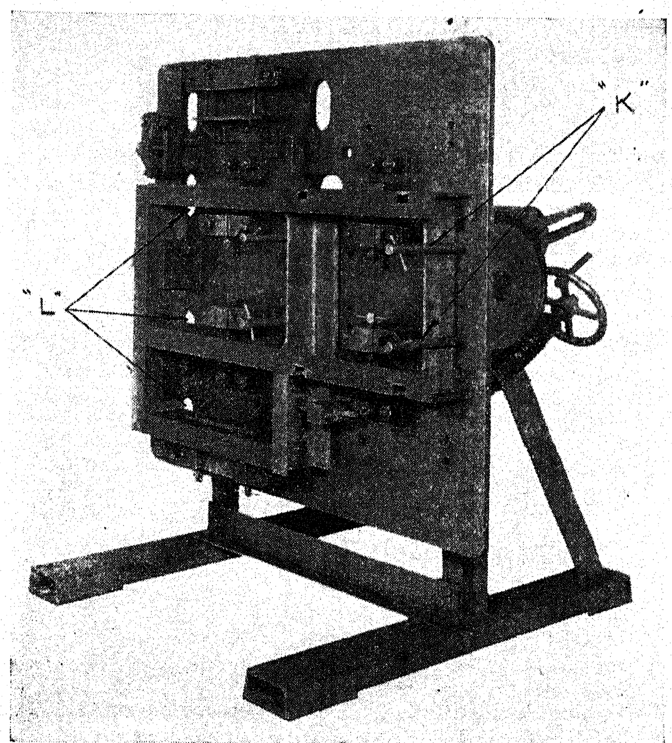


Fig. 3. View of fixture showing locating pins ("K").

used to build hundreds of satisfactory bed plates; economical because it saved approximately ten times the original cost of the fixture during the first year of use.

Advantages of the Assembling-and-Welding Fixture.—1, rapid and simple assembly of component members; 2, exact location and correct alignment of members; 3, eliminates the need for skilled layout men; 4, eliminates errors in reading drawings or transferring dimensions; 5, reduces distortion by properly holding parts during the welding process; 6, reduces cost of bed plate by reducing assembly and welding time; 7, permits quick removal of completely welded bed plate; and 8, insures a uniform product.

Description of Specific Features.—Fig. 1 shows the complete welding fixture with the table in the tilted position. The table may be both tilted and rotated to provide convenient positions for assembling and welding operations.

Special attention is called to the application of welded construction to the fixture itself.

ANNUAL DOLLAR SAVINGS

Resulting from Use of Welding Fixture

Assembled-and-Welded without Fixture		Assembled-and-Welded with Fixture		Saving
Layout & Assembling	$ 9.60	Assembling	$ 3.32	$ 6.28
Tack-Welding	.60	Tack-Welding	.60	
Arc-Welding Complete	12.00	Arc-Welding Complete	5.76	6.24
TOTAL	$22.20	TOTAL	$ 9.68	$12.52

Saving on Each Bedplate	$ 12.52
1937 Production of Bedplates	230
Gross Saving	$2,879.60
Less Cost of Fixture	250.00
Net Saving	$2,629.60

$$\frac{\text{NET SAVINGS}}{\text{COST}} \text{ RATIO} = 10.5$$

Self-Aligning Angle Stops, (Fig. 1).—The angle stops (A) are the basis of the aligning and clamping features of this fixture. Each angle stop is provided with two elongated slots in its base. These slots permit lateral movement of the angle stop so that it may be moved aside when the fixture is unloaded.

To reload the angle stop is restored to its normal position. Exact location and alignment are quickly secured by advancing the conical nut (C) into the conical seat (B) in the base of the stop angle.

Quick-Acting Clamps, (Fig. 2).—The loading and unloading time is greatly reduced through the use of quick-action clamps. These are shown in the open (D) and closed (E) positions. The clamps are of simple design. The clamp bar has an elongated slot (F) at the hinge end and an anchor toe (G) at the other end.

The clamp screw (J) holds the work in position by pressing the work against the angle stop and the clamp-bar toe against the anchor pin (H). A quarter turn of the clamp screw (J) is sufficient to release the clamp bar and permit it being slid back clear of the anchor pin and away from the work.

Locating Pins, (Fig. 3).—Pins (K) are used to temporarily locate the angle members of the bed plate. These pins are immediately removed after the angles are tack welded in place.

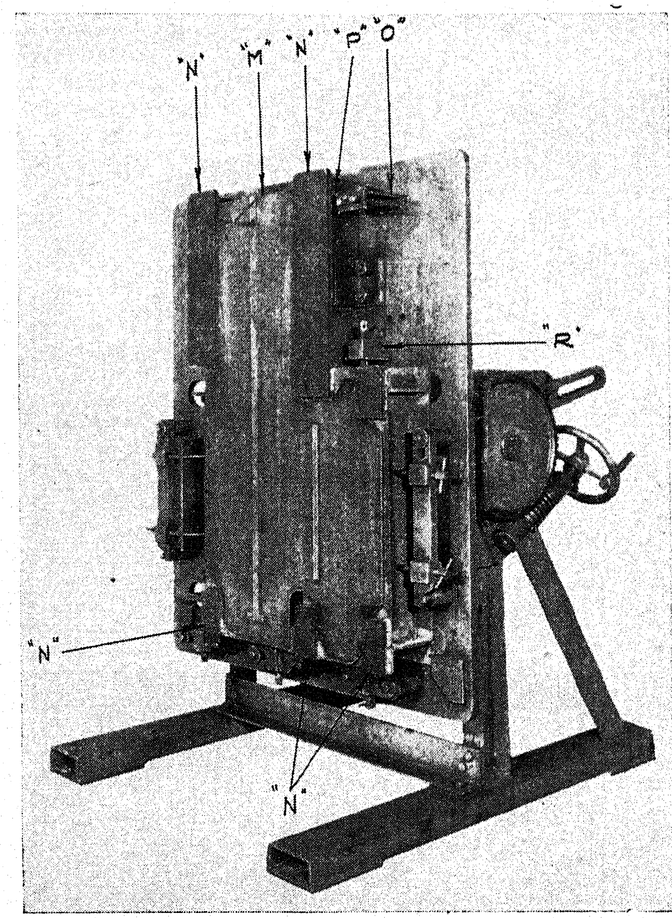


Fig. 4. Locating template "M" locates pads "N" for tack welding.

Locating Template, (Fig. 4).—Locating template (M) is placed on top of the bed plate to locate the pads (N) for tack welding.

Locating Gauge, (Fig. 4).—The removable gauge (O) is used to locate the stiffing plates (P) for tack welding.

Clamp Block, (Fig. 4).—This clamp block (R) is removable to facilitate unloading the fixture.

Relief Holes, (Fig. 4).—Relief holes are cut out in the fixture table to prevent the work becoming fused to the fixture during the welding procedure.

Complete Bed Plate, (Fig. 5).—Arc welded, the bed plate is one single homogeneous piece of steel.

A Thought for the Future.—This paper has described the successful application of a specific welding fixture to the fabrication of one type of bed plate. However, the principles contained herein and the specific features which have been described and illustrated are applicable to many other kinds of welded products. The scope of their application is limited only by the vision and ingenuity of the fixture designer.

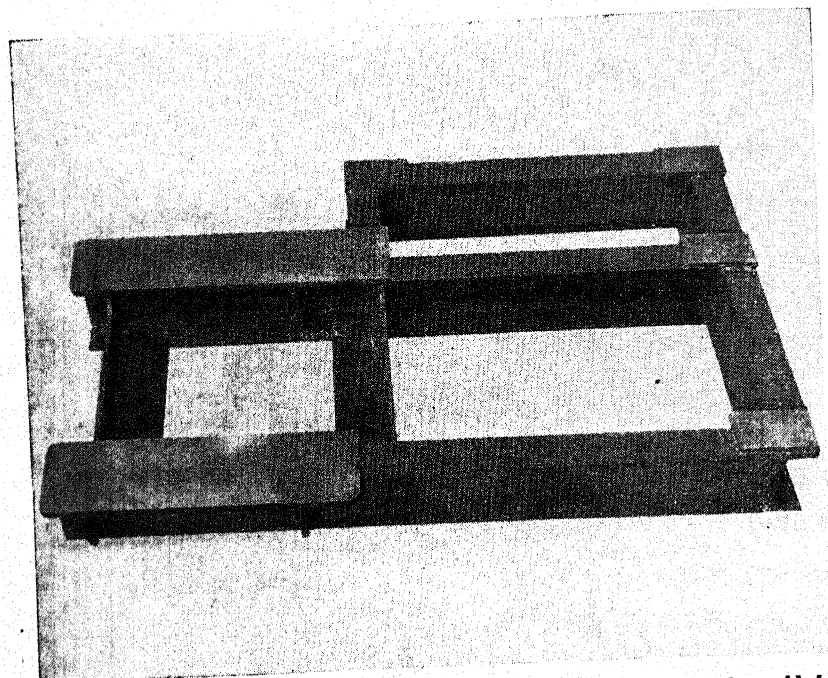


Fig. 5. Arc welded bed plate which is fabricated at great economy in the welded welding fixture.

Chapter V—Hardening Fixtures for Long Steel Strips

By George L. Kluter,
Tool supervisor, The Warner and Swasey Co., Cleveland, Ohio.

The hardening of long steel strips was a serious problem to the manufacturer of turning machines when the trade demanded hardened steel ways on their equipment. These strips are made of 2315 steel and have a section of 1/4 inch by 2 1/4 inches and a length of 5 feet 10 inches. They are machined all over and the screw holes drilled, then carburized and finally hardened by quenching in oil. In order to condition these strips for the grinding operations, it was necessary to straighten them on an hydraulic press, the average time required being one hour per strip, and in addition to this, the loss due to breakage at this point was prohibitive.

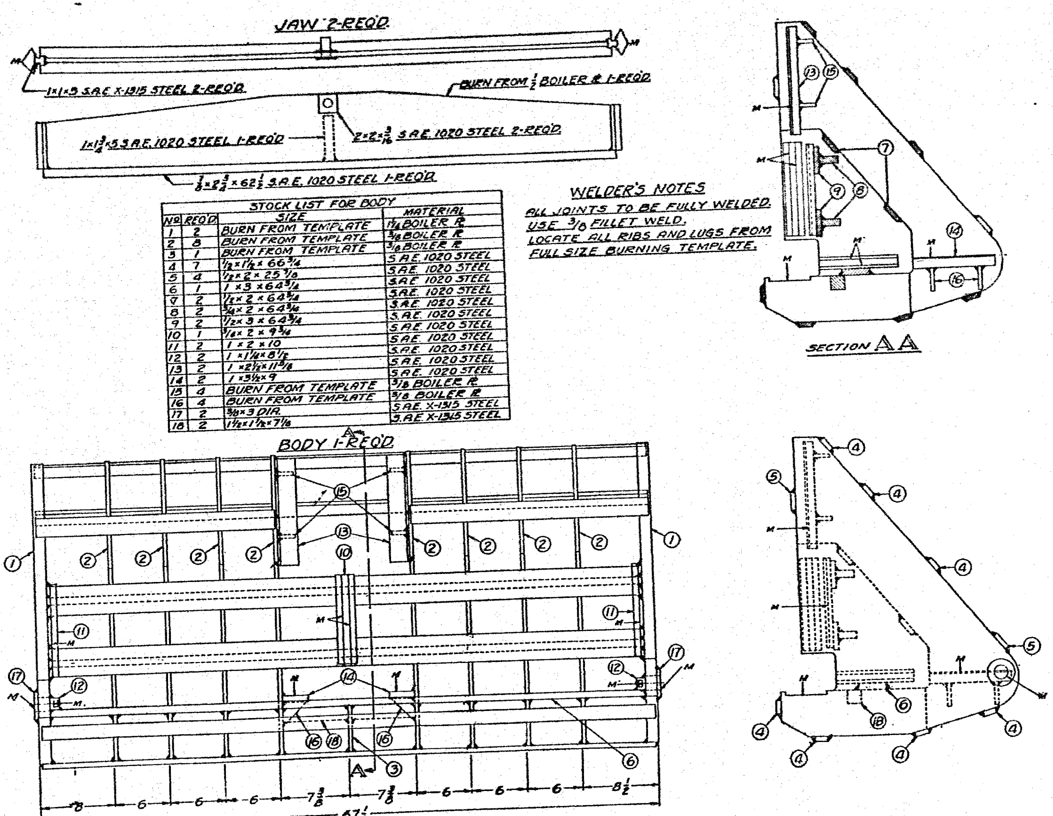
It, therefore, was necessary to develop and build a fixture to harden these strips under pressure to keep them from twisting and bowing. This fixture had to be light in weight to insure quick operating action, very rigid to hold the strips secure while cooling, and also had to be of skeleton construction to allow the maximum amount of oil to come in contact with the strip while being submerged.

With the above facts on hand and also the cost to consider, the next step was to decide how to construct this fixture to meet all the requirements. Cast construction was quickly ruled out due to the excessive cost and weight, and also the sacrificing of some of the open structure. Acetylene welded construction was decided against in anticipation of the trouble which would have developed in reaching in to weld all the joints. The arc welding method of construction presented itself as the only practical solution, to all those concerned.

The savings that were accomplished by this type of construction started in the tool design department. The designer can build up a construction of this type more rapidly with steel blocks and plates because the worries of coring and strength of overhanging lugs and close clearances due to draft on castings, are eliminated. The ribs can also be placed where they are needed most and their sections can be reduced anywhere from 25 to 50% and still accomplish greater rigidity.

The complete assembly design was laid out on a half scale drawing, of which the tool room and the welder received a blueprint. In addition to this, the welder received a blueprint showing only the welded construction. (See Fig. 1). This construction was made by merely tracing it on transparent sketch paper from the original assembly drawing, to which was added a stock list and the welder's instructions.

The welding department also received a full-size layout of all parts to be burned from boiler plate and, using these as templates, the parts were burned out to size on a pantograph type oxy-acetylene cutting machine. On these full-size layouts, all lugs, bosses and ribs which were to be welded in place prior to the assembly welding, were shown in their proper locations. This enabled the welder to place the sketch



STOCK LIST FOR BODY			
NO	REQ'D.	SIZE	MATERIAL
1	2	BURN FROM TEMPLATE	1 1/4 BOILER ℞
2	8	BURN FROM TEMPLATE	3/8 BOILER ℞
3	1	BURN FROM TEMPLATE	3/8 BOILER ℞
4	7	1/2×1 1/2×66 3/4	S.A.E. 1020 STEEL
5	4	1/2×2×25 7/8	S.A.E. 1020 STEEL
6	1	1×3×64 3/4	S.A.E. 1020 STEEL
7	2	1/2×2×64 3/4	S.A.E. 1020 STEEL
8	2	3/4×2×64 3/4	S.A.E. 1020 STEEL
9	2	1/2×3×64 3/4	S.A.E. 1020 STEEL
10	1	3/4×2×9 3/4	S.A.E. 1020 STEEL
11	2	1×2×10	S.A.E. 1020 STEEL
12	2	1×1 1/4×8 1/2	S.A.E. 1020 STEEL
13	2	1×2 1/2×11 5/8	S.A.E. 1020 STEEL
14	2	1×3 1/2×9	3/8 BOILER ℞
15	4	BURN FROM TEMPLATE	3/8 BOILER ℞
16	4	BURN FROM TEMPLATE	S.A.E. X-1315 STEEL
17	2	3/8×3 DIA.	S.A.E. X-1315 STEEL
18	2	1 1/2×1 1/2×7 1/8	

Fig. 1. Welded construction of hardening fixture.

on the plate after it was burned out and prick punch through for all boss and lug locations, thereby eliminating the laying out. In making these template layouts, the designer allowed 1/16 oversize on all edges to be burned, (to compensate for the width of the flame), and allowed 1/4 oversize on edges that required machining.

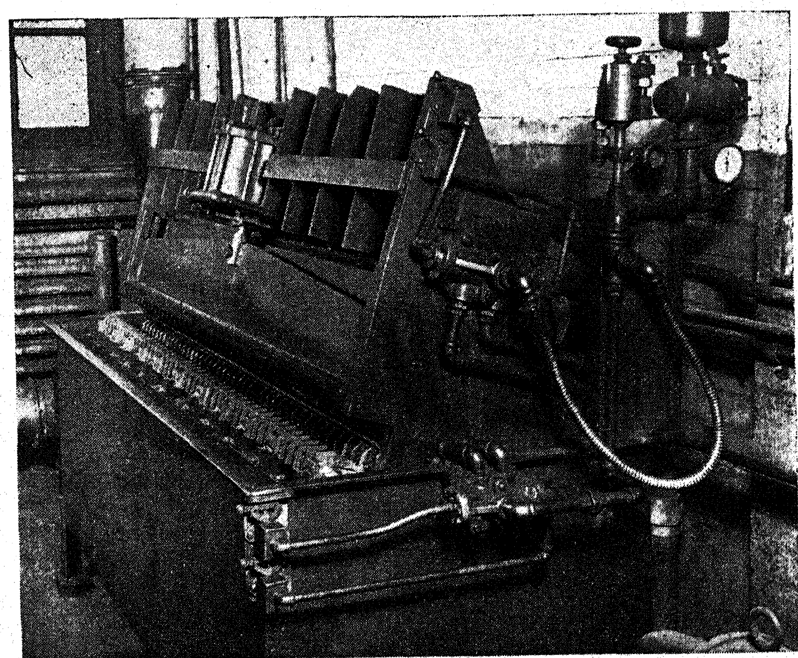


Fig. 2. Arc welded fixture for hardening long steel strips.

The set-up for assembly welding the fixture was made on the standard erection plate. This plate has machined T-slots 6 inches apart in both directions, and with a series of machined 90 degree knees, C-clamps and parallels, made the set-up quite simple.

In order to reach many of the joints which were welded, the operator welded two electrodes together (end to end) which worked very satisfactory, and also the covered electrode proved very beneficial in avoiding short circuits while reaching down through the framework.

The following table is a comparative statement of cost between the two possible methods of construction:

Arc Welded Steel Construction:—Actual

Burning steel plates & bar cut-off	4 hrs.	@ 1.75	$ 7.00
Set-up and tack welding (2 men 4 hours each)		@ 1.75	14.00
Finish Welding	6 hrs.	@ 1.75	10.50
Machining Time	95 hrs.	@ 1.75	166.25
Weight 1020 lbs.		@ .035	35.70
Annealing Treatment			10.20
TOTAL COST			$243.65

Nickel Cast Iron Construction—Estimated
(Competitive)

Estimated pattern time	110 hrs. @ 1.75	$192.50
Estimated pattern material 180 ft. of pine		45.00
Estimated machining time	90 hrs. @ 1.75	157.50
Estimated weight 1420 lbs.	@.07½	106.50
TOTAL COST		$501.50

$$\text{Ratio: } \frac{\text{Welded Steel}}{\text{Cast Iron}} = \frac{243.65}{501.51} = 48\%$$

The preceding cost statement is for the finished machined upper structure and jaw plates shown in Fig. 2. The tank was also made of welded steel construction, which, of course, would have been the only practical method regardless of the method chosen for the upper structure.

Fig. 2 also shows the hardened and ground stationary jaw inserts, (spaced 1½″ apart), which were mounted on two long steel shafts with eleven shaft support blocks. After these jaws were assembled to the shafts with the spacers and support blocks, the entire assembly was set in the finish machined slot in the body and the shaft support blocks welded in place. The hardened and ground inserts on the sliding jaws were made up in 10″ long sections and screwed and dowelled in place in the machined slot in the front of the welded jaw plate.

This fixture is operated entirely by air cylinders. Upon depressing the operating button, the rear jaw advances first, clamping the strip edgeways; then the top jaw comes down, using a pressure 50% greater than the rear jaw, thereby insuring perfect contact along the entire length of strip in both directions; then the submerging cylinder is put into action, lowering the entire fixture, which is pivoted on a fulcrum point near the rear end of the tank, into the quenching oil.

When the strip is cooled to about 300 degrees, it is removed from the fixture and requires no further conditioning for the finish grinding operations.

The savings realized through the use of this fixture during the year of 1937 were approximately $4200.00.

Chapter VI—A Tilting Fixture

By HAROLD F. WAHL,
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Acknowledgement.—The author acknowledges, with gratitude and appreciation, his indebtedness to Collis Johnson, General Manager, for his encouragement to vigorous endeavor, and for his constructive criticism; to Maurice Hooff, Factory Manager, for his technical suggestions.

Introduction.—Electric welding is simultaneously modernizing established industries and creating new ones. The Willamette Hyster Company, builders of lumber and logging equipment, is no exception. Welding has in many distinct ways revolutionized the manufacture of all of the company's products. The logging cruiser of the cast type shown in Fig. 1, has been replaced by an all-welded model.

The ultimate function of the cruiser is to do work. This work is done by reducing the normal tractive effort of dragging logs over ground. The cruiser principle of supporting logs at one end is so effective in its work function, that a "Caterpillar" tractor and a winch of proper size can easily handle amazing loads.

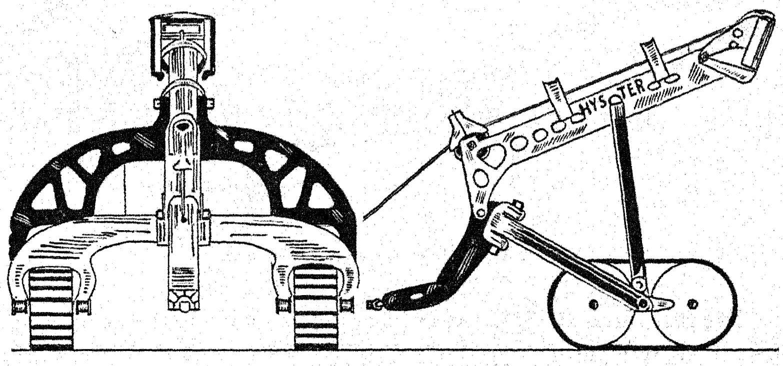


Fig. 1. Logging machine of previous cast construction.

The conservation of lumber resources is necessary if this nation is to continue to enjoy the benefits of the forests. The selective plan so adept to conservation lends itself admirably to cruiser type logging; however, it demands of logging equipment the lightest possible weight with ample strength and ruggedness.

The desirable strength versus weight ratio of the cruiser design was accomplished by using a welded box type of fabrication. This type of construction is simple. Butt and fillet welds are used entirely.

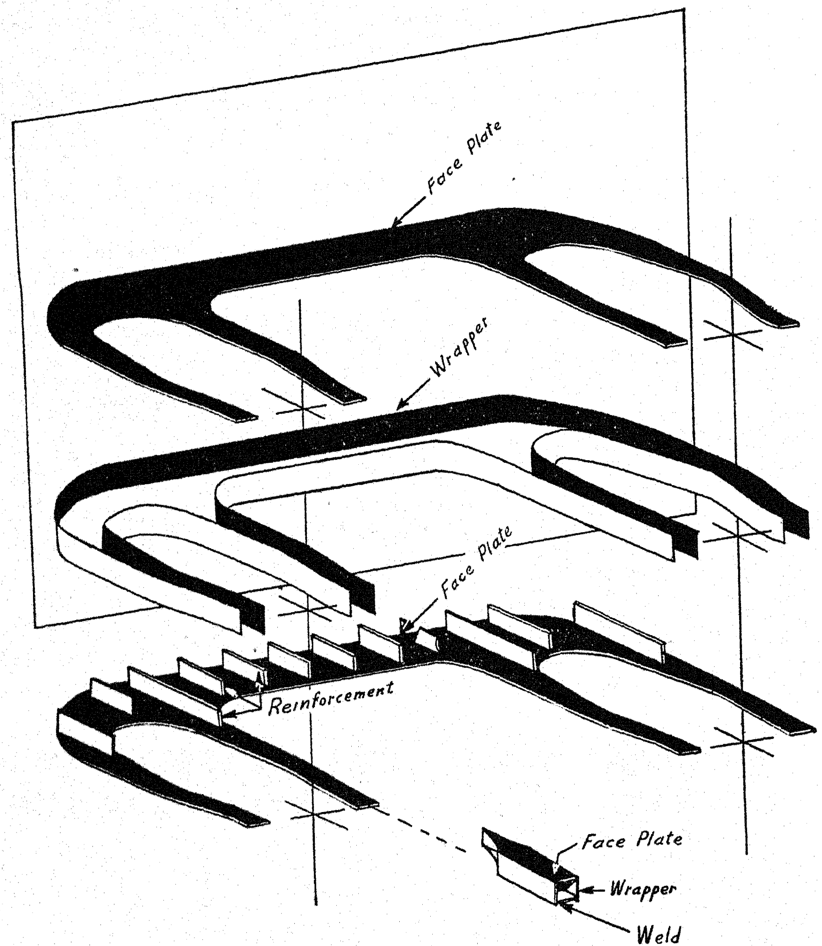


Fig. 2. Face plates form cruiser tongue.

The face plates of Fig. 2, when arranged as shown in the detail with the wrappers in place, will form a cruiser tongue. The construction of the arch is identical. The parts called arch, tongue, and boom are defined as shown in Fig. 3.

The technique of welding the cruiser parts is in no way unusual. The first pass is made with 1/8 or 3/16 inch rod; the second is of 1/4-inch. The thickness of the plate material in no case exceeds 3/8 inch. Mild steel welding rod is used almost without exception. Stress relief annealing and preheating of Man-Ten welded plates is not used. The comparatively small thicknesses make such techniques unneccessary.

The minimum radius for the design of wrapper plates on the box section construction is 5 inches. Sharper radii than 5 inches may cause fatigue failure zones. This value is given for design that must endure

severe stress conditions such as one would find in the normal operation of a cruiser. It is known that a D8 cruiser (the largest model) is capable of being manipulated over stumps and logs with a 30,000 pound load suspended from its fairlead. This welded structure is then subjected to tremendous shock loads.

It is intended in this introduction to briefly describe one of the Hyster products. The welded logging arch is without a doubt a unique application of an all-welded construction. However, like most products, there are certain characteristic problems. Fundamentally, the welding of the boom, tongue, and arch of a cruiser, as individual units, is quite comparable in every respect. One would say that the task of burning, tacking, and arranging prior to the finished welding is equal in each. Moreover, it is a fact that there is a striking cost differential

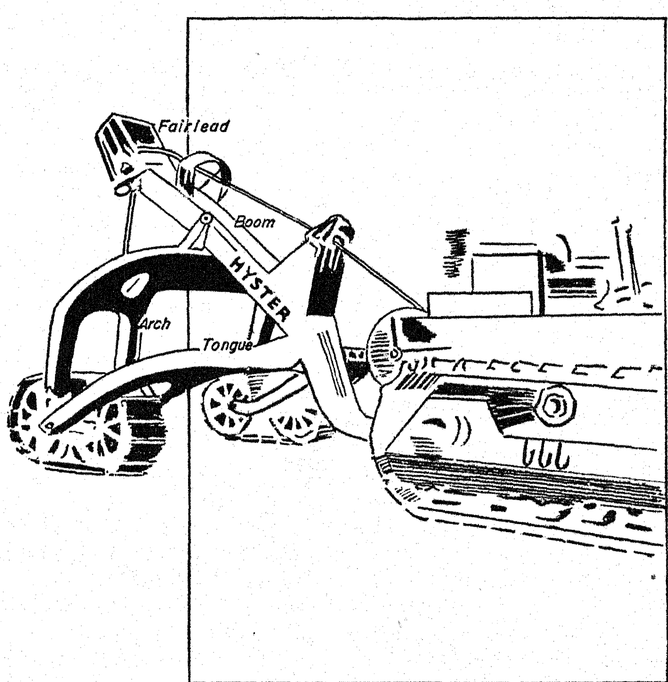


Fig. 3. Principal parts of logging machine.

between the welding of a boom and an arch, or a boom and a tongue. The question of cost in any factory is a most pertinent one, but seldom is the matter of refinements in manufacturing an easy problem to solve.

It has been very well established by this study that the 84 feet of welding on the boom can be done in 8 man hours, or at a rate of 10.5 feet per hour, while 119.2 feet of welding on the tongue can be done in 16 man hours, or at a rate of 7.45 feet per hour. It is seen that the tongue is being fabricated at a rate 29% slower than the boom. These basic figures are in their simplest comparative form, without the

many variations which could be introduced as a part of a time study.

Since these two parts are made of identical materials and welding, there is but one logical reason for this cost differentiation. The boom can be more readily manipulated into desirable welding positions than the tongue. Any scheme of production that would attain the welding speed on the arch and tongue equal or better than the boom, would be a worthwhile advance. The arch or tongue face plates can be cut from a 6 x 12-foot plate, and compared to the boom with its 1-foot width the problem of getting desirable welding positions is obvious.

The fundamentals of cruiser construction have raised one of the most common and important fabrication problems. This paper is contributed with the hope that the art of arc welding is benefitted, and that those having similar problems will find application in what is humbly described in the following pages.

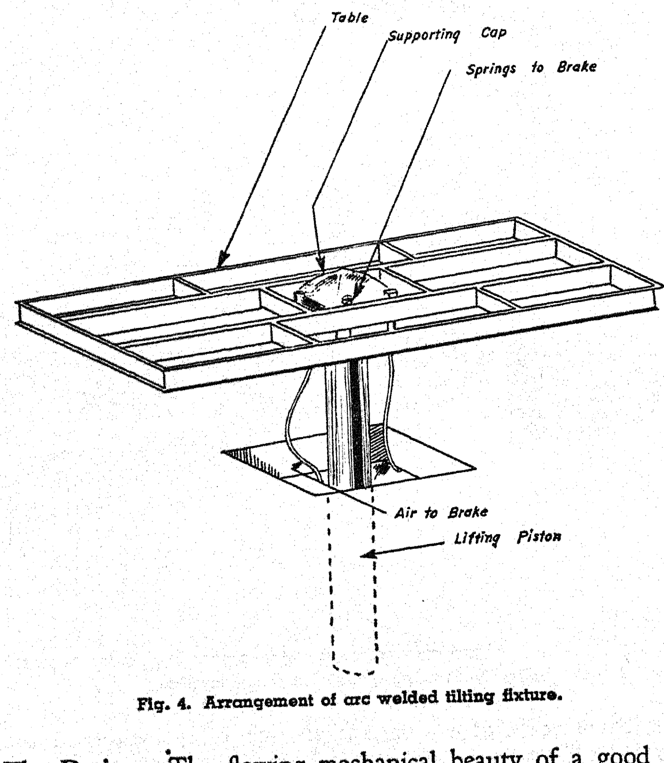


Fig. 4. Arrangement of arc welded tilting fixture.

The Design.—The flowing mechanical beauty of a good welded structure has an absolute minimum of welding. Lapped joints, plug welds, or other characteristics of rivet construction are seldom seen in good welded design. In this type of design, the loading develops eccentric features in all but very special conditions. Butt and fillet welds predominate in good welded design with the stresses literally flowing symmetrically through such a structure. If the engineering design is fundamentally sound, and the drawings ideographically correct as to

welding specifications, there remains but one requirement for the fabrication of a quality product.

A good set-up is essential to good welding. Work can proceed quickly and surely under such conditions. The welding rod is then about 45 degrees to the wrapper and face plate for a fillet weld. Such are the conditions when the welder can make equal legged fillets having a minimum of convexity. Besides costing money in wasted welding rod, the convex fillet weld is of no mechanical benefit.

The good set-up for the fabrication of the cruiser arch and tongue is a problem. A tilting fixture for such a product must be flexible, safe, and productive. Let us for sake of argument correlate the description of the jig with these prerequisites.

The flexibility of a tilting fixture is fundamental. Modern industry is familiar with several variations of basic designs for tilting welding jigs. The inclined plane of the rotating type, the hinge and quadrant type, all aim at obtaining the ideal welding position. They have their good and bad features. Their cost, space requirement, and limitations as to working positions cannot be listed as commendable features. However, the ball and socket type fixture which is being described is expensive, requires a minimum of space, and attains the ultimate with regard to tilting positions. The sketch, Fig 4, shows the general construction of the jig.

The detailed construction of this unit is as simple as the general appearance of this drawing. The supporting table is shown in the horizontal position. The one supporting column is an ordinary air-operated piston as used in automobile service station lifts. Any horizontal position up to 6 feet is permissible. The table is held in this or any angular position up to 45 degrees with the horizontal by means of an air brake. The fixture is located in the shop so that it may be served by the overhead crane.

The welders in this plant work in pairs. One may operate the air brake and lift, while the other makes the necessary changes in positions. Anyone familiar with welding a box section will recognize that in order to keep warping at a minimum, the temperature gradient which results from welding should be equal at the same time along correspondingly opposite welds. Practically, this ideal condition can only be approached either by manipulating the work quickly, or by very clever tack welding. Since the rate of radiation of the hot weld is something of the order of the fourth power of the absolute temperature, it is essential that work proceed quickly.

Just why this tilting fixture moves easily is shown in the detailed sectional arrangement drawing, Fig. 5. The cast iron cap rolling on the 80 steel balls, which ride in the hardened seat, offers little resistance to a motivating force. The average load on these steel balls is about 3000 pounds. One finds that if a force as large as 100 pounds is required to move the table, the work has not been properly located on it. The jig stops are so arranged that the center of gravity of the work is on the same vertical line which passes through the center of gravity of the jig.

The cast steel ball 24 inches in outside diameter, shown in detail,

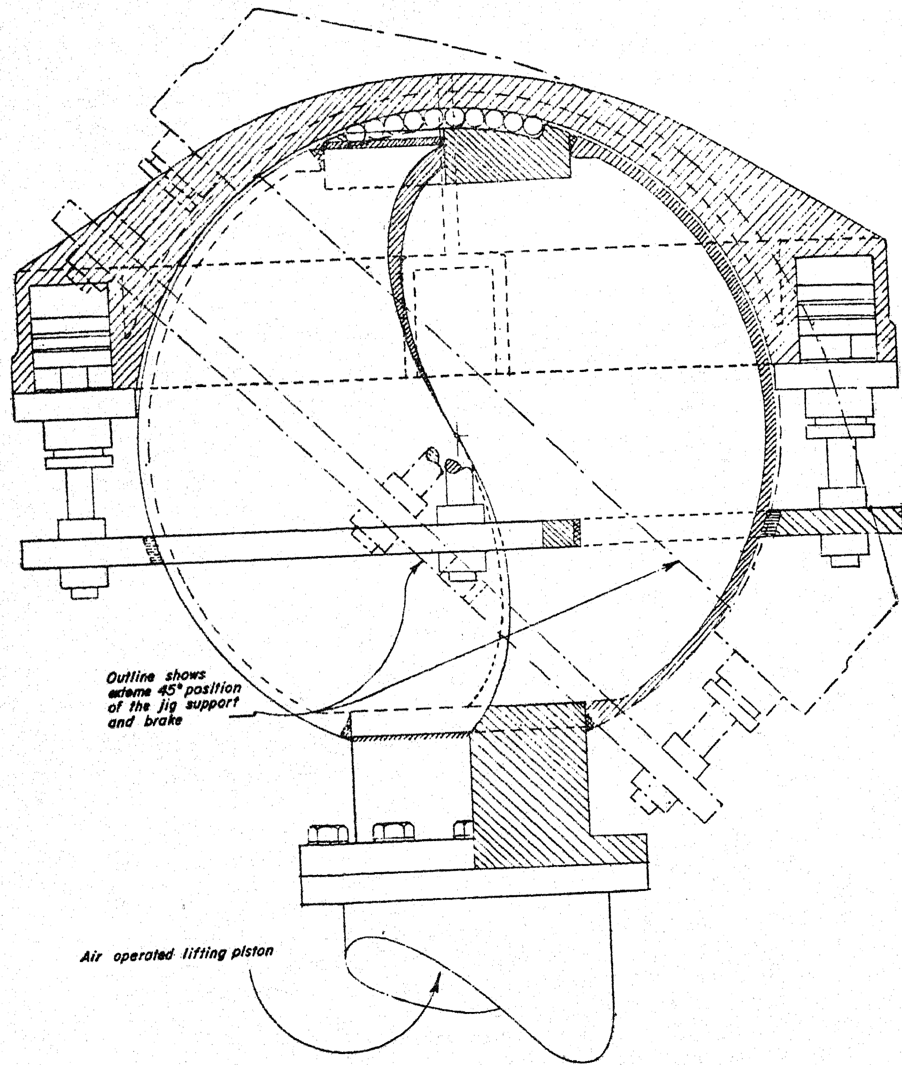


Fig. 5. Sectional arrangement of tilting mechanism.

Fig. 6, is open at both top and bottom. The 9½ inch diameter opening is provided for the hardened seat, while the 8¾ inch opening is for the face which fastens to the lifting piston. It is the combination of welding and casting that makes this design possible. Obviously, the casting of the ball, seat, and base in one piece is not feasible. The patterns for the entire job cost $75.00 when using an open-ended sphere. The ⅛-inch tolerance between the supporting cap and the pivot ball is ample. The detail drawings of the cap, and the hardened

seat, are seen as Figs. 7 and 8. The flat flange surface $12\frac{1}{2}$ inches from the center of the cap provides a surface for fastening the table channels.

The second prerequisite for a good tilting fixture is safety. The safety of this fixture depends on a rather novel application of an air brake to the geometrical properties of a sphere. Perhaps it might be of interest to discuss this phase of the fixture in its mathematical aspect.

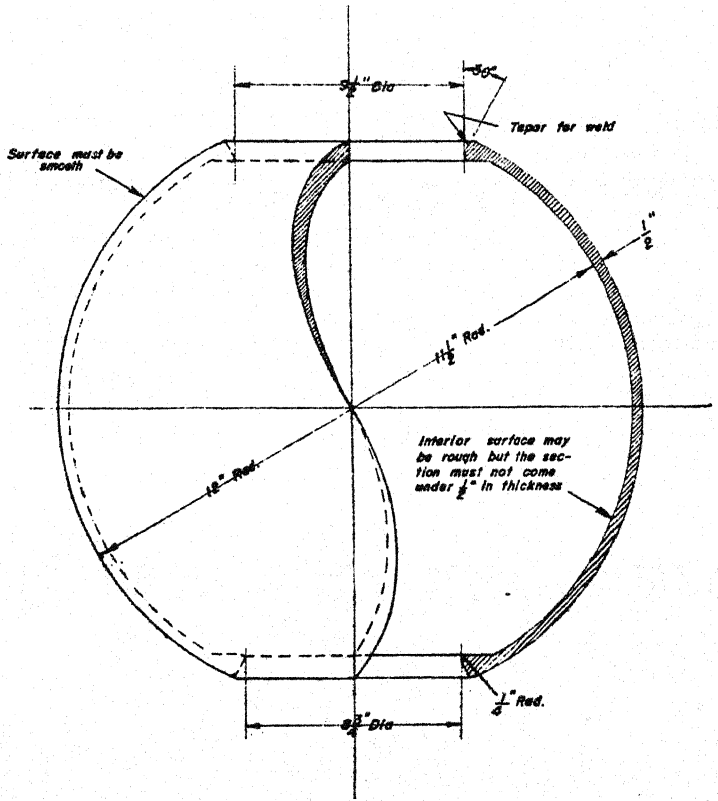
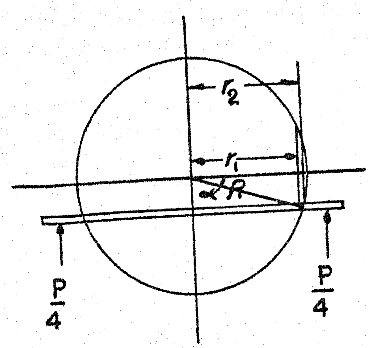


Fig. 6. Cast steel supporting pivot ball for tilting fixture.

The tangent of a sphere will intercept a horizontal plane passing through its center. This angle can be made to vary from zero to 90 degrees. Somewhere in this range is the proper location for the brake. Referring to the drawing of the arrangement of the air brake, Fig. 9, note the position of the brake. The radius from the center of the brake will include an 18 degree angle with the horizontal. Angles of 14 degrees cause the brake to stick after the braking effort has been released.



If we consider the above diagram in which P will be the total magnitude of the applied air force, then at each quadrant of the brake we will have a ¼ P. Further, let,

$p =$ the unit normal pressure at the contact surface
$c =$ the coefficient of friction

For the sake of simplicity, let us assume that our braking surface is narrow enough that we might consider the surface as straight. The normal force acting upon an elementary strip is

$$2\pi rp \frac{dr}{\sin \alpha}$$

The component parallel to the line of brake action is

$$2\pi rpdr$$

The force of friction upon the elementary strip is

$$2\pi cr \frac{dr}{\sin \alpha}$$

Since we have already restricted ourselves to considering only a very narrow brake, we may set up limits of integration as between r_2 and r_1. Then

$$P = 2\pi p \int_{r_1}^{r_2} r\, dr = \pi p\, (r_2^2 - r_1^2)$$

$$M = \frac{2\pi cp}{\sin \alpha} \int_{r_1}^{r_2} r^2 dr = \frac{2\pi cp}{3 \sin \alpha} (r_2^3 - r_1^3)$$

If we make substitutions in our moment equation for the unit pressures, we can obtain M in terms of P, the total pressure, or

$$M = \frac{2cP}{3 \sin \alpha} (r_2 + r_1)$$

but the sum of $(r_2 + r_1)$ is the mean diameter D, so

$$M = \frac{2cPD}{3 \sin \alpha}$$

for moments in the horizontal plane.

The springs shown in the sketch drawing of the general arrangement of the tilting fixture, Fig. 4, were figured so that 4 of them in compression would supply the same load as the 4 pistons pulling on the brake. A larger force can be exerted in releasing the springs, than in applying the brake. The effort of the springs must be completely overcome for the entire release of the brake. The brake used as a safety device on the tilting fixture is always applied to half the total possible braking effort, should the air line fail, which is sufficient to hold a normal load.

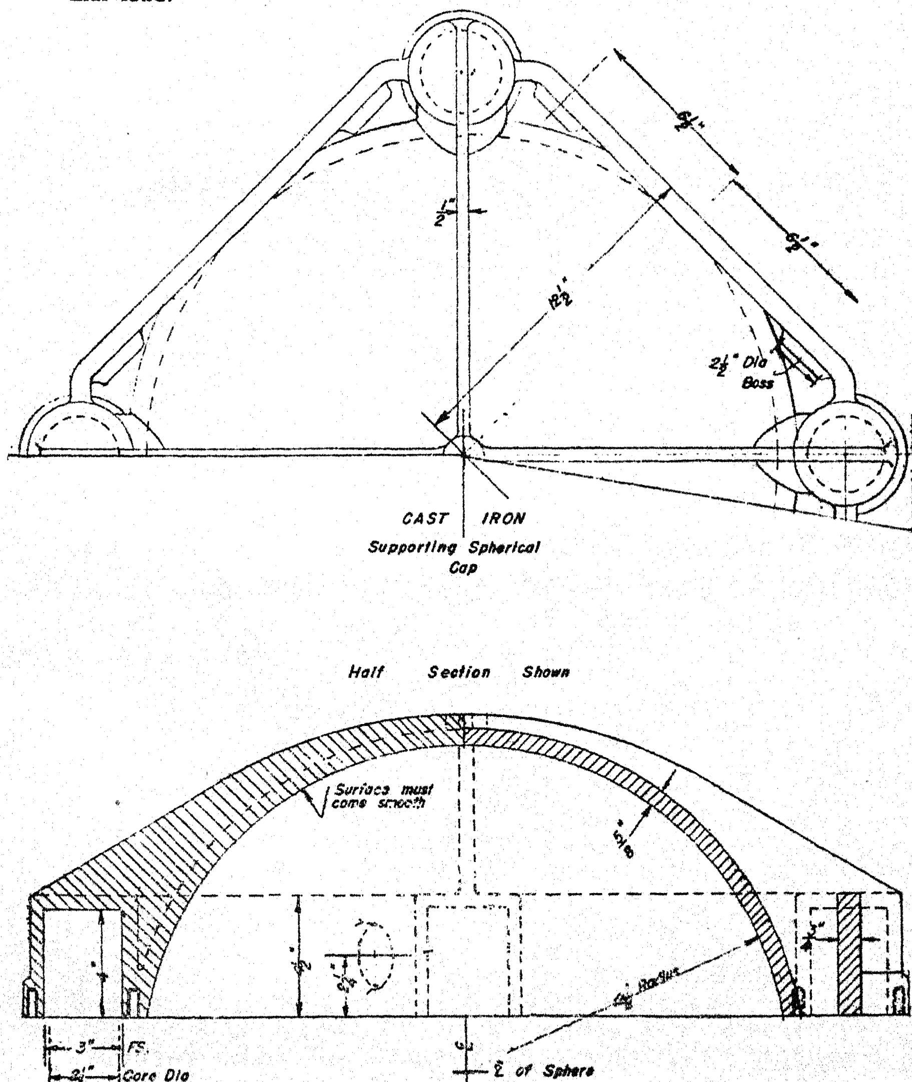


Fig. 7. Details of cap.

Substituting the values,—4000 pounds as the resultant of 80 pounds of air on the 4 pistons, plus the sum of the 4 springs in compression, .4 as the coefficient of static friction, and 23 as the mean diameter of the brake at 18 degrees,—the brake develops a moment which will resist 3000 pounds at 6 feet. This is the moment in the horizontal plane. The moments taken about any other axis besides the vertical can be analyzed to the satisfaction that the fixture can endure 12 times the eccentric loading that can be handled manually. We draw the conclusion from this analysis that the fixture is safe.

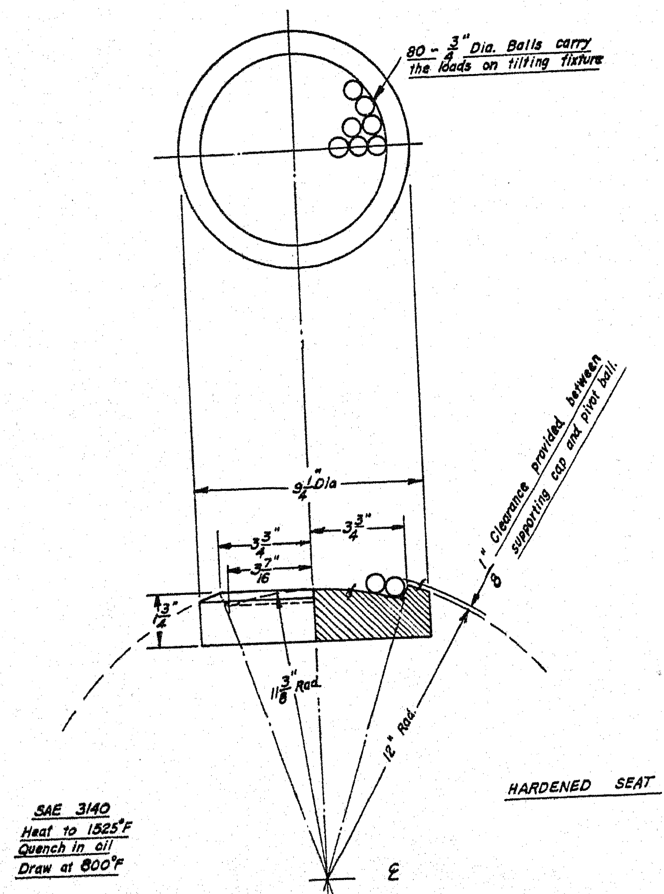


Fig. 8. Details of hardened seat.

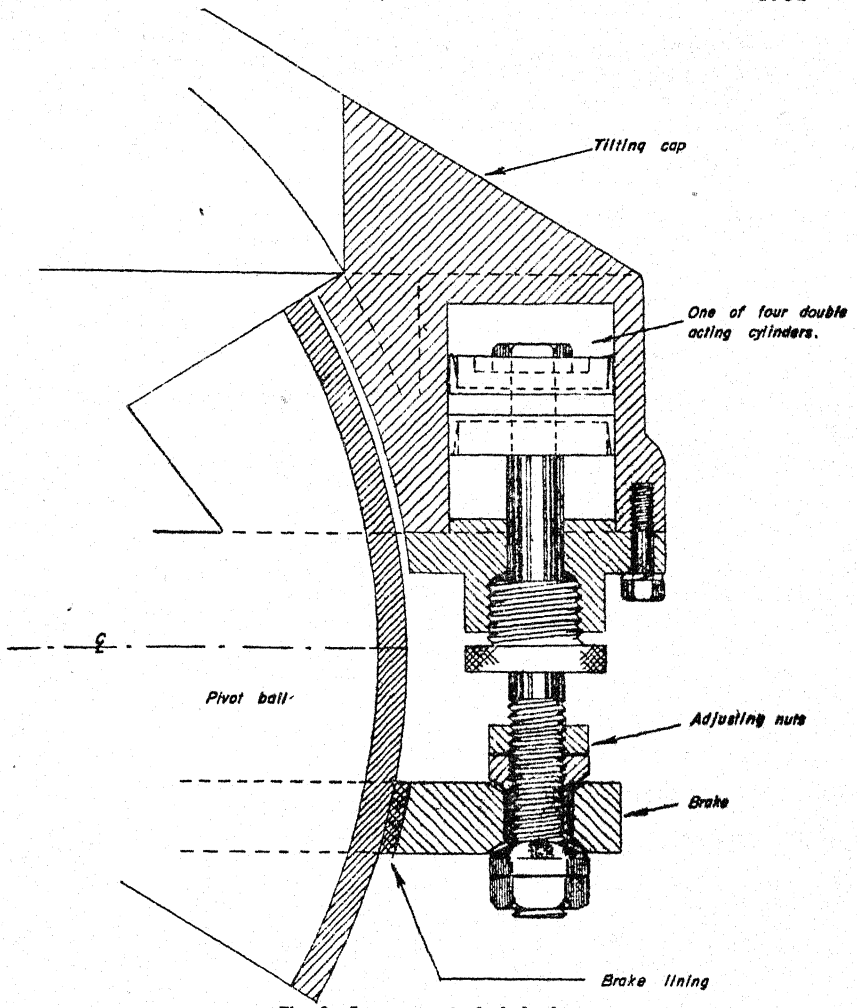


Fig. 9. Arrangement of air brake.

The final prerequisite requires that the fixture be productive. Increasing the rate of welding the cruiser arch and tongue to that of the boom has been accomplished. New uses are continually being found for the fixture. Stops for welding the boom have been added with good results. The complete savings the jig offers are almost overshadowed by the quality of the work it permits. There is perfect efficiency developed in the fillet welds around the contour of the cruiser parts. The fillet welds are equal legged and flat. The welds on the cruiser are the finest to be found on any welded product. The use of this jig is the necessary final touch in improving the general excellence of the cruiser. It allows the use of fast welding rod on otherwise mild welding rod jobs, besides being a base on which other smaller units might be mounted.

Conclusion.—The following points might be considered in the growing category of welding fixtures for general welding practice:

(1) The profitable production of a welded article depends on proper design, an absolute minimum of necessary welding, and a good welding set-up that will allow a welder to do the assigned job quickly and perfectly.

(2) The fixture described is successful in at least three phases:
- (a) It allows the use of a fast welding rod;
- (b) It is extremely flexible and safe in any welding position;
- (c) It makes possible the production of the perfect weld, which by virtue of the symmetry of the weld develops 100% efficiency with a minimum of necessary welding material.

Chapter VII—Revolving Adjustable Tilting Table Chuck

By B. A. Jacobs,
Welder, Phillips Petroleum Co., Bartlesville, Okla.

The revolving adjustable tilting table chuck as outlined in this paper is a new design of a machine, not previously made or generally used or ever sold before January 1, 1937. Nevertheless the machine has been designed, tests have been made, and a number of the machines are in constant use today.

This revolving adjustable tilting table chuck, as illustrated in Fig. 1, is manufactured from salvaged automobile parts and standard materials as designated.

The cost of all materials for a machine as pictured which does not include the vertical protractor or bubble glasses, amounts to approximately $60.00 and may be arc welded and assembled ready for use by one welder and one welder's helper in 8 hours. To include the protractor and bubble glasses will add a few dollars to the cost of the machine, and which may be more than warranted in certain classes of work.

With the standard rate of pay to a welder and a welder's helper it is possible to produce the revolving adjustable tilting table chuck complete and ready for use at a cost of considerably less than one hundred dollars, $100.00, that being understood to mean a machine as shown in pictures herewith, which does not have the added features of protractor or bubble glasses.

The machine might be constructed partly in a different manner by using other than salvaged automobile parts which would be more costly and not so substantial or practical.

The small amount of wear in the reclaimed, but naturally well tested, automobile parts has no bad effect on the operation of the machine; and strength, and utility, and satisfactory performance are assured. Arc welding is essential in the manufacturing of the machine, and the machine is essential in arc welding.

To make the most satisfactory arc welds with the equalization of deposited metal on the two objects being united, the table is tilted at any desired angle and rotated at desirable speed, with the location of the rod fixed, thus assuring a uniform, penetrating, increased deposit of metal in a neat finished appearing arc welded joint. Fig. 1 illustrates how the revolving adjustable tilting table chuck handles such conditions.

In arc welding with this machine a uniform and constant speed develops a uniform deposit of metal. The machine as illustrated is manually operated and controlled, but same may be motor driven. Electrical power for instance may be developed by the exciter which may be made a trifle larger on the arc welding machine.

Any kind of a rod may be used, for the angle of the machine may be adjusted for proper puddle, so that the puddle is always on the top and by such a method more metal is deposited. Puddle marks are prac-

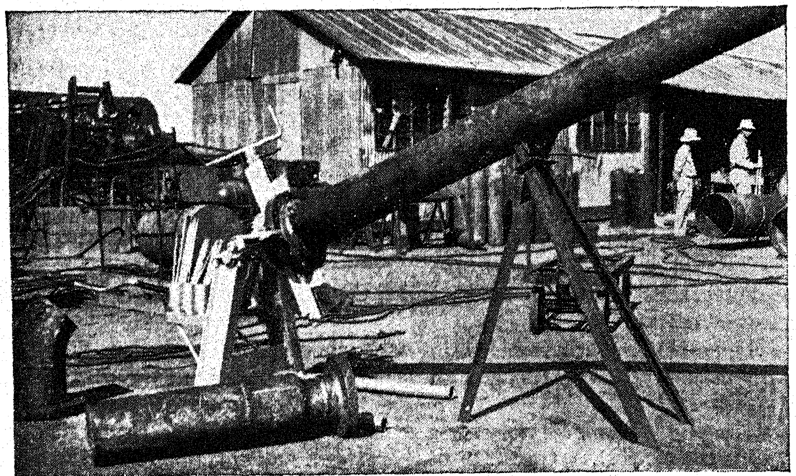


Fig. 1. Arc welded adjustable tilting table chuck.

tically eliminated. Very satisfactory appearing arc welded joints are the result, not to mention the tremendous strength which is added to the joint.

One other of the many advantages in the use of this machine is the fact that the joint may be tacked and rotated for check to assure the welder that the parts are in their true relative positions. Whereas, by other methods heretofore used, inaccurate joints were too numerous and often could not be used.

The use of this revolving adjustable tilting table chuck has proven to be very profitable. The savings in labor is over 35%. Definite examples are described herewith. Not only is the machine profitable to the user, it has other important advantages. Work may be done standing or sitting in a natural position. It is a luxury to the workman, who by the way need not be an expert. Unlimited advantages may be experienced in all industries in which a rotary, or tilting, or both actions are necessary or may be utilized.

For instance this machine was used in the making of a standard eight inch (8″) orifice meter setting to be used in gas lines.

The comparative costs of making the fore-mentioned meter setting can be realized from the following facts:

First, by the old method, the work being done on dollies or rollers, one welder and one welder's helper worked 8 hours each to complete the arc welding for one meter setting complete.

Secondly, by the new method in which the revolving adjustable tilting table chuck was used, the same welder and his helper were able to do the same work of a better quality in just 5 hours. This means a saving of 37½% in labor.

To appreciate the use of the new machine we must never lose sight of the old inconvenient methods, one of which is illustrated in Fig. 2. In said picture you will observe the old dolly rollers and wood block which

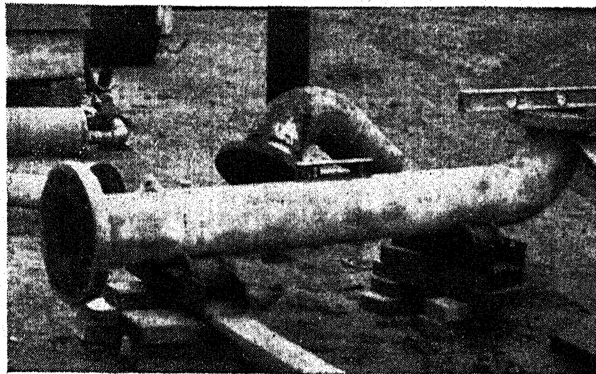


Fig. 2. Old method using dolly rollers and wood block.

never did prove very agreeable. You can compare this old fashioned way with the newly developed method of handling work as is being done today with the revolving adjustable tilting table chuck, shown in Fig. 1.

Another good example for the comparative saving by use of the revolving adjustable tilting table chuck was in the making of a pump header as shown in Fig. 3, the facts being as follows:

In making of the pump header, one welder and his helper worked 9 hours on dollies and arc welded 24 eight-inch series 30 flanges. During the same period of 9 hours another welder and his helper using the revolving adjustable tilting table chuck arc welded 44 eight-inch (8″) series 30 flanges. This represents a saving of over 45% in labor, and also an increased quality of the job by using the newly developed machine. To be sure, no information was given to the men that comparisons were

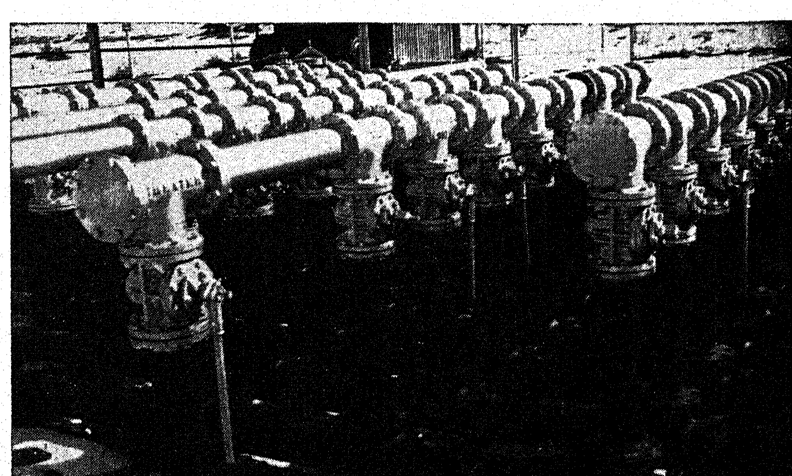


Fig. 3. Pump header, construction of which was speeded by arc welded table chuck.

being made. The men on dollies were equally matched in qualifications and experience with the men using the revolving adjustable tilting table chuck.

It is natural that the welders and their helpers should want the new machines. Twenty such machines have been made by one company and are in constant demand, by the men employed with said company.

The reasons for the demand isn't doubtful in the least. A frequent job of repairing a cog wheel is handled easily with the newly developed rotating adjustable tilting table chuck. It is only a case of turning the crank to have the next cog up into the proper position for its required application of metal with no delay in waiting for cooling or danger of hand burns as was so constantly annoying and often times proved disastrous when there was no such machine or its makeshift neighbor.

And too, how many times has a welder failed to properly repair a sheave in his attempt to do so by the use of the old-fashioned methods? As a matter of fact we now have the machine which makes the job in reality very easy. The rim of the sheave is simply turned or rotated, the arc is fixed, the puddle is on top at all times during the process of making the repair, thus assuring a perfectly satisfactory result.

And with the newly developed slip on flanges for electric arc welding, the revolving adjustable tilting table chuck has proven to be of unlimited advantage. This is only another one of the many economical uses for the recently designed machine which the arc welder has needed for a long time, and which is not limited for the size of the job to which it may be applied. To the welder, the revolving adjustable tilting table chuck may mean more than a Brazilian Diamond.

Chapter VIII—Arc Welded Dies

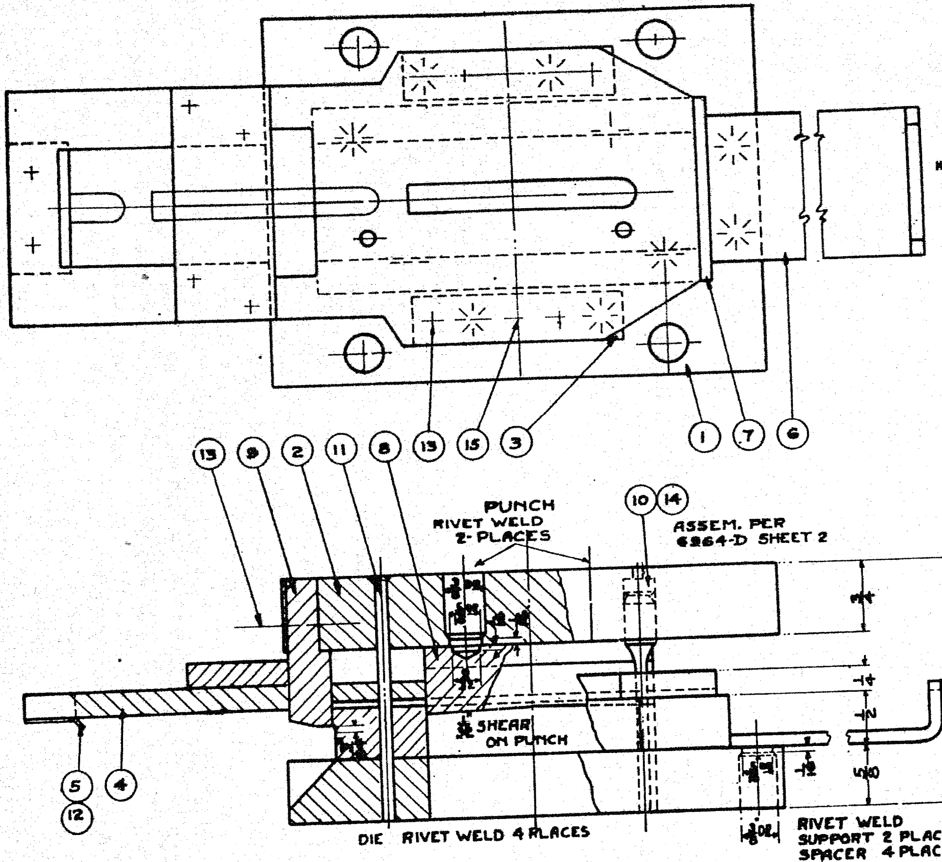
By H. A. Sedgwick,
General superintendent, Cutler-Hammer Inc., Milwaukee, Wis.

An increasing trend toward the use of costly alloy steels in the construction of metal piercing, blanking, and forming dies, and the ever-present desire that such tools be produced as cheaply as possible led to an extensive study of die types, specifications and identification of material used, drafting methods, labor content, and inspection practice. Out of this investigation came indications of possible changes in routine, conservation of materials, and reduction of labor which might be utilized to accomplish the desired results.

This paper will deal with only one of the factors used to cut costs by reducing in quantity the expensive material used, and the labor expended. Briefly, the scheme revolves around the use of arc welding in the fabrication of the various dies named, and the elimination of the usual die set for each finished die.

In the usual approach to the manufacture of a plain or common blanking die, a drafting layout is made from which is selected a proper sized die set and to the elements of this die set, to wit, a punch holder element and a die holder element, (arranged so that by the use of proper leader pins and bushings they may coact in definite relationship to each other), are attached, by means of screws and dowels, the particular tool steel punch and die elements which have been prepared for the production of a certain stamped article. These pages indicate up-to-date, approved, latest practices in the production of punch and die elements.

The introduction of hold-down screws and fitted dowels has necessarily increased the labor content of a particular die assembly by the amount of time required first, to make the screw and dowel holes, and second, after hardening of the punch and die elements to carefully transfer such holes to the die set so that the upper punch and lower die elements may properly align. Shrinkage or slight distortion of the punch or die elements in hardening usually proscribe the possibility of the transfer of such holes from punch and die elements to die set elements while such punch and die elements are in an annealed or unhardened state. The slight distortion noted may be responsible for the expenditure of labor for the purpose of lapping dowel holes to roundness and straightness after hardening of the elements and before transferring of the screw and dowel holes to the die set is at all possible. In the end a die assembly emerges with the punch element attached to the punch holder element of the die set, and with the die element attached to the die holder element of the die set, and, as a result of the toolmaker's skill and his labor expended, the assembly is a complete working unit with the punch element entering smoothly and accurately into the die element so as to produce a desired result.

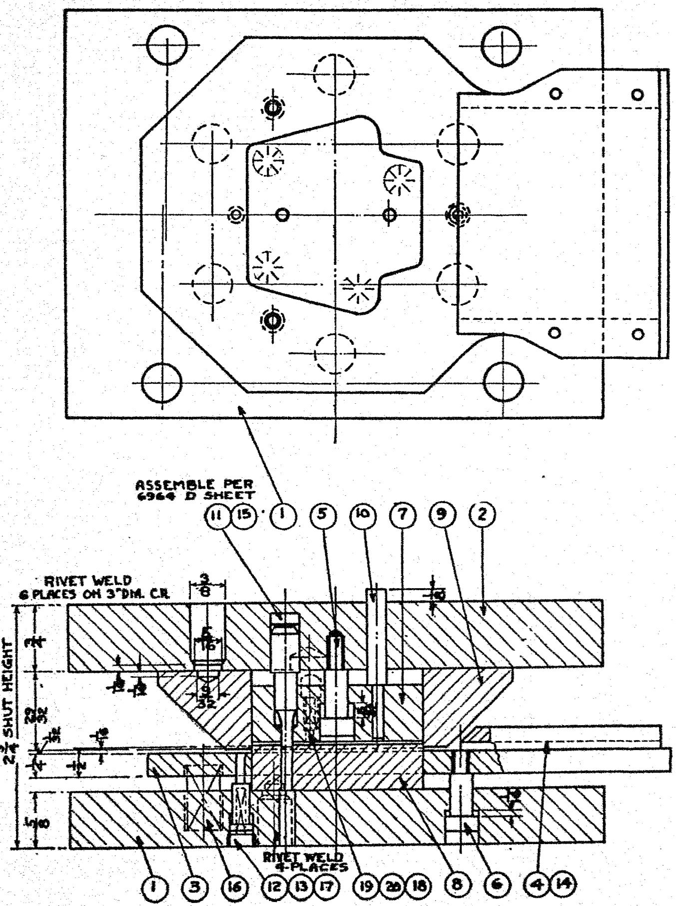


.032 x 1 3/16 BERYLLIUM COPPER 2 5/8 APPROX LEAD.
USE 5" UNIVERSAL DIE SET No 43481
No 1 3/4 NIAGARA 1 1/2 STROKE 120RPM HAND FEED

	ITEM NO	NO REQ'D	NAME OF PART	PCS REQ'D	SIZE OF MATERIAL REQ'D		STR MATL NO
HDN	16	1	BACK PLATE	1	1/4 x 1 x 2 1/4	GEO. STK	1396
	15	2	DOWEL	2	3/16 DIA x 1		703
	14	1	PUNCH LOCK SCR.	1	1/4-28 x 5/16		1075
	13	6	SKT. HD. SCR.	6	10-32 x 3/4		1646
	12	6	RIVET				
HARDEN	11	1	PILOT	1	#28 (.139) DIA x 4 3/4	DR ROD	903-3069
HARDEN	10	1	PUNCH	1	5/16 DIA x 1 5/8	SOLAR 35	1912
HARDEN	9	1	CUT OFF PUNCH	1	1/2 x 1 1/2 x 1 5/8	BETH xx1	1237
HARDEN	8	1	PUNCH	1	3/4 x 3/4 x 2 1/2	BETH xx1	1215
HARDEN	7	1	DIE BLOCK	1	1/2 x 1 7/8 x 4	LEHEIGH 12	1468
	6	1	SUPPORT	1	1/8 x 1 1/2 x 5	CRS	906-798
	5	1	PLATE	1	1/32 x 1 1/2 x 7/8	CRS	906-722
	4	1	STRIPPER	1	1/4 x 3 x 7	CRS	906-227
	3	2	SPACER	1	1/2 x 1/2 x 4 1/4	SCR. STK	905-761
	2	1	PUNCH PLATE	1	3/4 x 4 x 8	CRS	1545
	1	1	DIE PLATE	1	5/8 x 3 3/4 x 5	CRS	1706

ROUND PUNCHES MUST BE GROUND ALL OVER

Fig. 1. Pierce and cut off die.



ITEM NO.	NO REQD.	NAME OF PARTS	PCS ORD.	SIZE OF MATERIAL REQUIRED	ST. or PATT NO.
20	1	PLUG	1	8-32 × 1/8 RD. HD. SCR.	911-417
19	1	BLK. EJECTOR PIN	1	#27 (.149) DIA. × 1/4 DR. ROD	903-3068
18	1	SPRING	1	.135 DIA. × 1/2	969-3027
17	1	SPRING	1	3/64 DIA. × 17/32	69-443
16	6	SPRING	6	13/32 DIA. × 1 5/16 CUT TO 1 1/8 LG.	969-1121J
15	2	PUNCH LOCK SCR	2	1/4-28 × 5/16	1075
14	4	RIVET	1	1/8 DIA. × 3 SCR. STR.	903-201
13	1	STOP PIN	1	1/4 DIA. × 1 DR. ROD	903-3103
12	1	PLUG	1	CUT FROM 5/16-18 × 1/4 RD. HD. SCR.	911-1292
11	2	PUNCH	2	5/16 DIA. × 1 5/8 SOLAR 35	1912
10	4	PUSH ROD	1	#11 (.188) DIA. × 8 1/4 DR. ROD	903-3052
9	1	PUNCH	1	1 × 4 × 4 BETH. × × 1	1257
8	1	DIE	1	1/2 × 2 7/16 × 2 1/8 LEHEIGH #12	1469
7	1	K.O. PAD	1	3/4 × 2 × 2 1/2 BETH × × 1	1247
6	3	STRIPPER BOLT	}	3/8 DIA. × 5 SCR. STK.	903-601
5	1	STRIPPER BOLT			
4	1	GUIDE	1	1/4 × 2 1/4 × 3 1/4 CRS	906-950
3	1	STRIPPER	1	1/4 × 4 × 6 CRS	906-228
2	1	PUNCH PLATE	1	3/4 × 4 5/8 × 6 CRS	1547
1	1	DIE PLATE	1	5/8 × 4 5/8 × 6 CRS	1707

.032 × 2 3/16 WIDE C.R.S. × 2 LEAD
2A NIAGARA 1 3/4 STROKE 110 R.P.M. INCL'D. HAND FEED
USE WITH 6" UNIVERSAL DIE SET NO 43482

ROUND PUNCHES MUST BE GROUND ALL OVER

COMPOUND PIERCE & BLANK DIE
MOUNTING BRACKET

Fig. 2. Compound die.

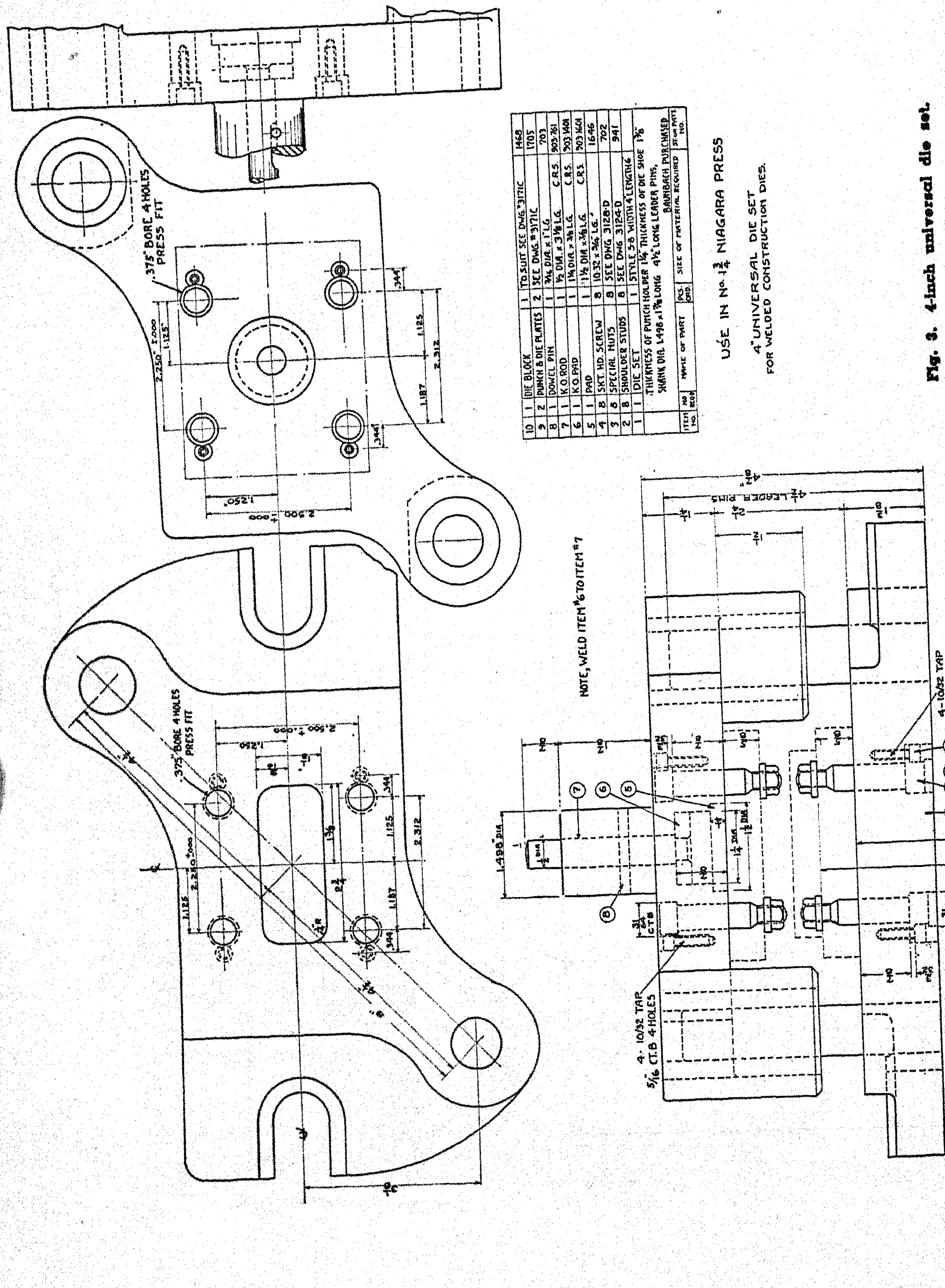


Fig. 3. 4-inch universal die set.

As a result of the study before mentioned, the writer, assisted by our tool supervisor, devised, put into experimental practice, and finally although experiments are still going on, has brought to a production basis for the fabrication of dies similar to those described above, the before-noted method which will now be described more in detail. While, for clarity, reference is made to a plain or common blanking die only, it is to be here noted that nearly all types of pierce, blank, and form dies have been constructed, including single and double, two-position pierce and blank dies, (See Fig. 1), pierce, form, and blank dies; and compound dies, (See Fig. 2), in which inner and outer contours of a certain piece are blanked at the same time.

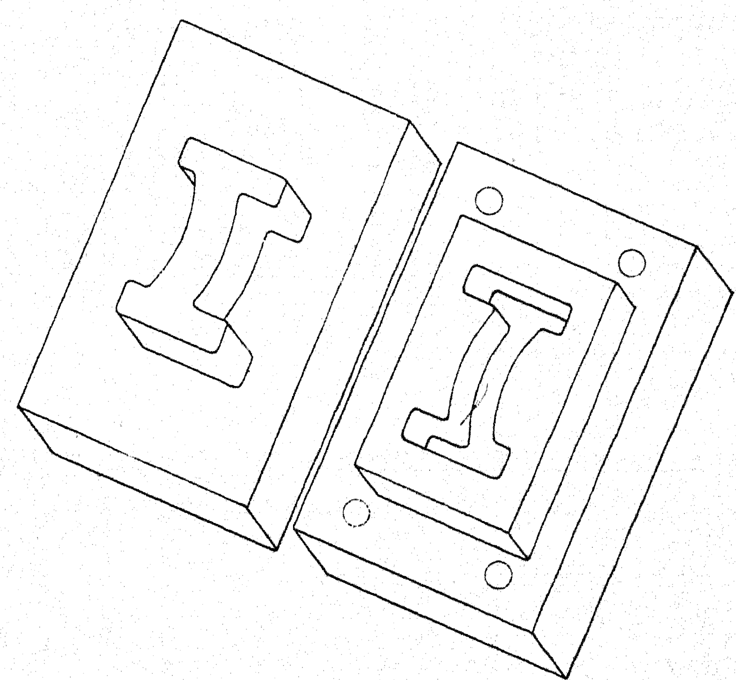
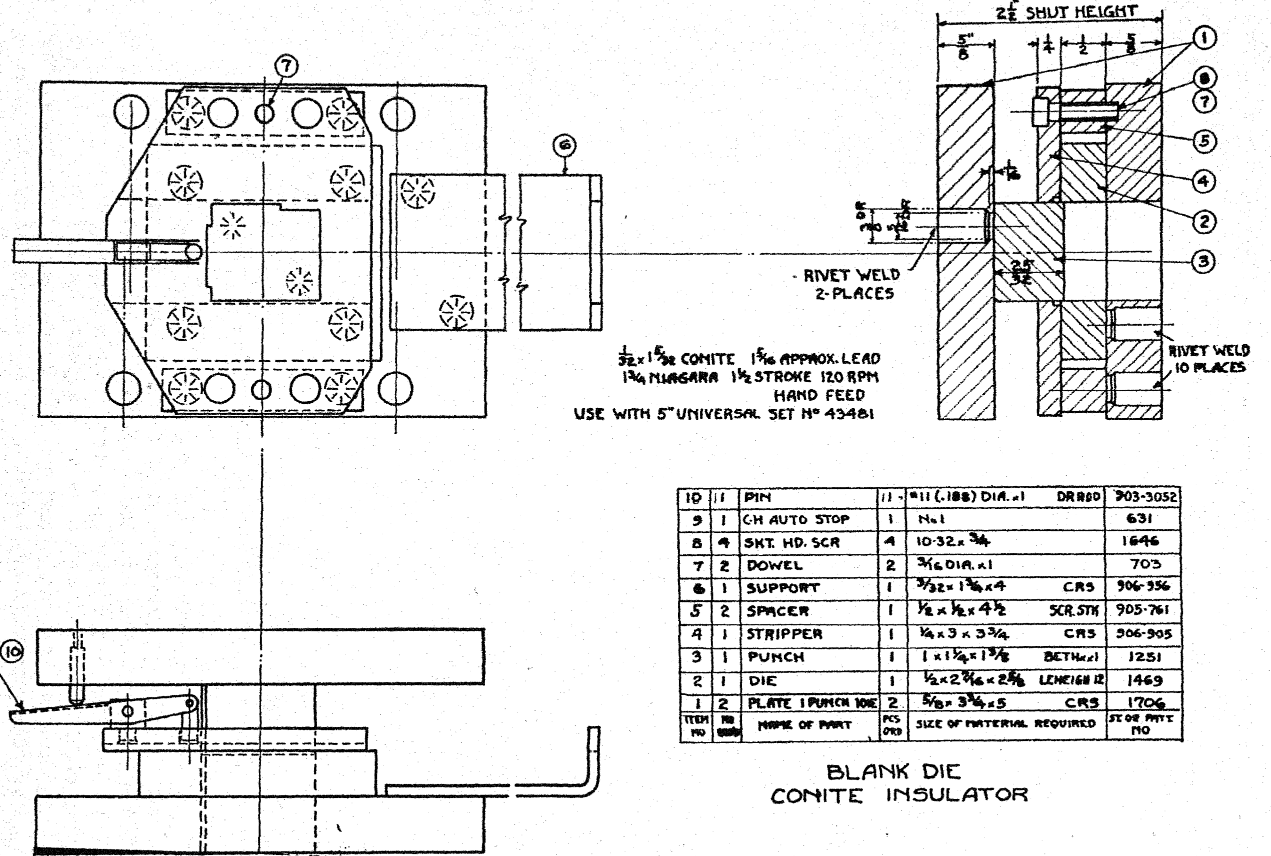


Fig. 4. Perspective of punch and die elements welded to backing plates.

The process utilizes, besides the blocks of tool steel heretofore mentioned as punch elements and die elements, two soft or low-carbon steel blocks of substantial area and of medium thickness, known and referred to hereafter as backing plates. The two plates required are previously machined to size, with others, in a quantity lot and have each been provided with two dowel and two hold-down holes by which they may respectively be accurately located on to a punch holder member or a die holder member of a conventional die set by means of dowel bolts previously inserted into such die sets by usual means. All this is indicated on Fig. 3 herewith.

Punch and die elements are made of pieces of carbon or alloyed tool



ITEM NO	NO REQD	NAME OF PART	PCS ORD	SIZE OF MATERIAL REQUIRED		ST OR PART NO
10	11	PIN	11	#11 (.188) DIA. x 1	DR ROD	903-3052
9	1	C.H AUTO STOP	1	No. 1		631
8	4	SKT. HD. SCR	4	10-32 x 3/4		1646
7	2	DOWEL	2	3/16 DIA. x 1		703
6	1	SUPPORT	1	3/32 x 1 3/4 x 4	CRS	906-956
5	2	SPACER	1	1/2 x 1/2 x 4 1/2	SCR. STK	905-761
4	1	STRIPPER	1	1/4 x 3 x 3 3/4	CRS	906-905
3	1	PUNCH	1	1 x 1 1/4 x 1 3/8	BETH x 1	1251
2	1	DIE	1	1/2 x 2 7/16 x 2 5/8	LENEIGH 12	1469
1	2	PLATE 1 PUNCH 1 DIE	2	5/8 x 3 3/4 x 5	CRS	1706

BLANK DIE
CONITE INSULATOR

Fig. 5. Blanking die.

steels. In the case of the punch of such size as to conform to the outline of piece to be made, and in the case of the die element of somewhat larger dimensions but usually quite less than that required when dowel holes or hold-down holes in the die element are contemplated, the thickness of the tool steel elements is arbitrarily reduced below that used in common practice because they are to be mounted on the two low-carbon steel backing plates heretofore described.

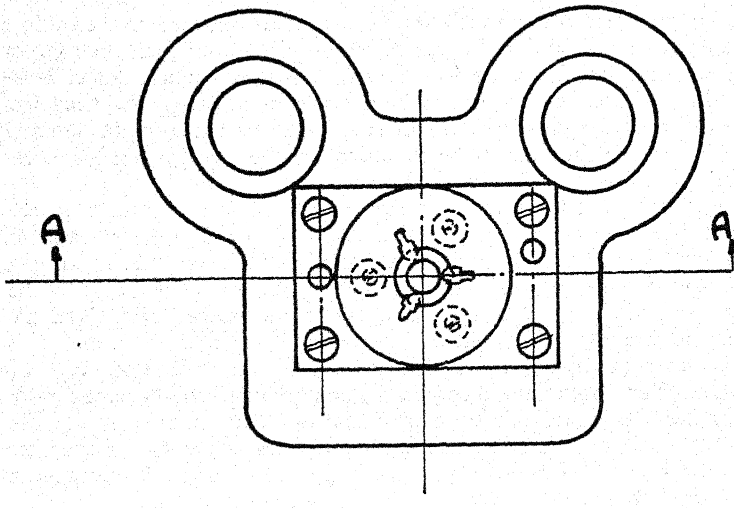
By constructing the punch element with an area no larger than the product piece to be punched, and with no flanges, it is possible to utilize power operated machines of the endless file type, first in sawing the contour from the plain piece of tool steel, and succeeding this by the file in bringing the punch approximately to its finished size. The die element is likewise sawed out by the endless saw and the contour is likewise brought to very nearly finished size by the endless file type of machine. Here note that recognized good practice in die work now utilizes these types of machines in connection with work on the die element, but as may have been inferred, does not make use of them in work on the punch element because the presence of flanges thereon makes it impossible to do so.

After working out on the two types of machines noted, a punch element and a die element may look as per Fig. 4, which is a perspective intended not only to show the two tool steel elements with the entire absence of flanges of any sort, but especially to indicate that there are no hold-down holes or dowel holes in either element. Very little, if any, bench or hand filing need be done in order to reduce the two elements to a required condition of accuracy before hardening and tempering. After the hardening and tempering process, the two pieces of steel are stoned or honed until they are perfect conjugates of each other, and with a minimum of clearance or difference of size as may be required. With no flanges this stoning or honing may also be done quite largely upon the power-operated machine. When the stoning has been completed the tool steel elements are ready to be permanently attached to the above mentioned low-carbon backing plates.

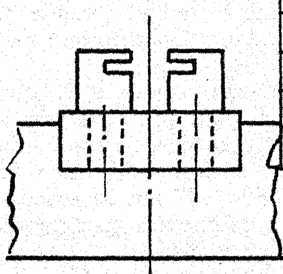
Previous to the actual attachment of the tool steel elements to a backing plate, said plates have been prepared by drilling therein two-diameter holes at approximate locations as are indicated on a drawing of an assembled die, Fig. 5. The approximate position of the holes is shown by a wheel symbol. The operation of providing these holes require no accurate workmanship in depth or size or location, and therefore may be done in a minimum of time.

When the two backing plates have thus been prepared it is usual to place the tool steel die members on one of them approximately as indicated in Fig. 4, and securely weld them thereto by the use of the arc welding process, providing what is termed a rivet weld, using for such rivet, alloy steel welding rod materials which will not be seriously affected by the heat of the weld and which will retain good tensile strength characteristics after welding has been completed.

This step of the work is usually done without a jig of any kind, but with one or more clamps used to retain the die element in the position upon the backing plate in which it was placed for the welding operation. With the die element firmly welded to one of the backing plates, such



IT. NO	NO RQ.	NAME	PO	SIZE	
15	1	STRIPPER	1	½×2×2	RUBBER
14	4	DOWEL	4	¼DIA.×1⅜	DANLY
13	8	SKT. HD. SCR.	8	¼ 28×1	ALLEN
12	1	K.O. ROD	1	13/16 DIA.×3	SCR. ST.
11	3	K.O. PIN	1	.227 DIA × 5¼	DR. ROD
10	1	DISC	1	1½ DIA × ½	BETH.
9	1	PUNCH	1	23/64 " × 1½	DR. ROD
8	1	K.O. PAD	1	¼ × 1 × 1	GRD. ST.
7	2	GUIDE POST	1	⅜ DIA × 3	SCR. ST
6	1	PUNCH	1	1¼ × ¾	LEHIGH
5	1	DIE	1	2 × ¾	"
4	1	SHIM	1	.020×2 3/16×2	CRS
3	1	PUNCH PL	1	⅝ × 2 × 7	CRS
2	1	DIE PL			
1	1	DIE SET	1	3×4-51	



TO BE USED IN #18 BLISS PUNCH PRESS 1½ STROKE 120 R.P.M. INCL'D ROLL FEED .025 C·R·S· 1" WIDE × ⅞ LEAD APPROX.

Fig. 6. First die designed. See also page 1393b.

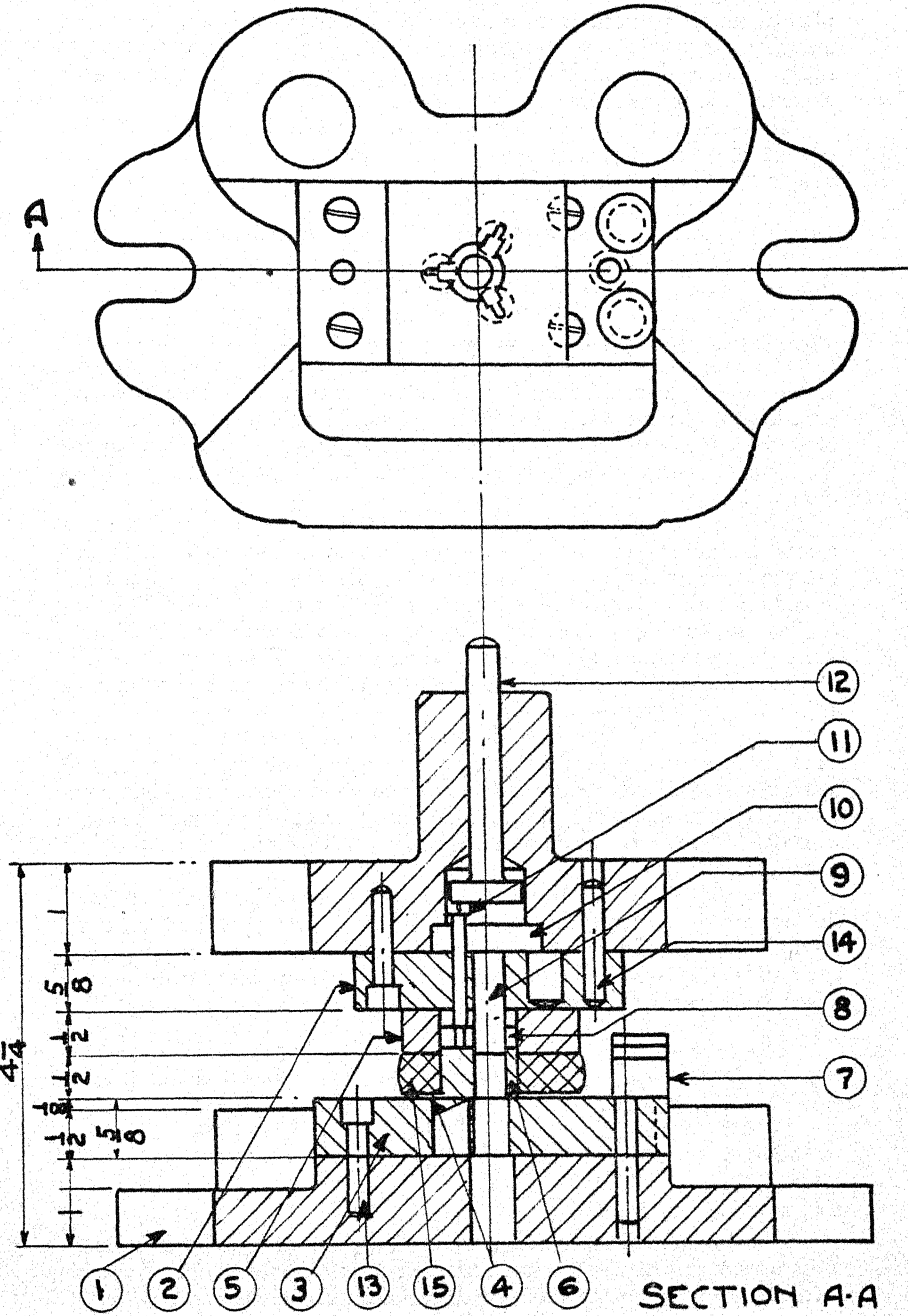


Fig. 6. First die designed. See also page 1393a.

plate is placed in position in a master die set retained in the tool room, and in which the dowel bolts, Fig. 3, are in absolute similar relation to those in die sets permanently located in punch press machines in shop departments, in one of which later the die will be used.

This master die set is in all respects like those in the shop departments except that it has no punch stem, so-called, but rather both in the punch holder element and in the die holder element holes have been machined through, which have removed nearly all the metal of such die set elements within the rectangle bounded by the dowel bolts themselves.

After placing the one backing plate with the die element welded thereon in the master die set, the second backing plate is placed in exact relation upon the dowel bolts of the punch holder element while both are lying on the bench. The die set is then put together as for use, the tool steel punch element is inserted into the tool steel die element approximately 1/16", being restrained from further entrance by small tool steel parallels of approximately 1/16" less vertical height than the thickness of said die elements. The exact positioning of the punch element in the die element is accomplished by well-known means and is, therefore, not discussed here.

After attainment of an accurate relationship of punch and die elements, the punch element is welded in place on its backing plate as was the die element previously. The two backing plates are now removed intact with their respective punch and die elements and look exactly as illustrated in Fig. 4. Thereafter, stripper plates, low-carbon steel guide strips, etc., are added, also by the welding process. This assembly is sent to a shop department and is mounted into a punch press with permanently adjusted die set therein for use.

It was assumed that in a die of this construction, because less of expensive tool steel would be used for the punch and die elements, and less labor ought to be expended in fabricating the structure, that costs would be correspondingly lower than in our regular previous designs. In order to prove this assumption, a careful check was made on the first three dies.

These dies were actually designed in what up to that time had been the approved construction, and estimates were prepared according to regular practice. The dies were also designed in the new construction and prints of this construction were sent to the shop without estimates. The results were as follows:

	Cost Per Previous Construction	Actual Cost of New Construction	Percentage of Cost Savings
No. 1	$162.82	$ 99.34	38.9%
No. 2	186.73	122.62	34.3%
No. 3	140.00	87.48	37.5%

Or an average of 36.9%.

As a further check, some twelve dies were designed for welded construction, and at the the same time blueprints of the various product parts were sent to several tool shops with designing ability and capacity, and they were asked to design and estimate costs on their own design. The result of a check of these figures against actual cost figures obtained

in the welded die construction indicate that an average of over 30% in savings might confidently be expected.

Here is a type of die construction, then, which may be applied to 60% or more of all small or medium pierce, blank, or form dies made in the country, with great possibilities in larger dies as yet unproved because of lack of opportunity. It is not hard to visualize the relatively large and continuous savings which may be realized by the use of this method. The more prominent savings which may be claimed are as follows: reduction of expensive material used, reduction in time required for fabrication, reduction of hazard in hardening, and, incidental to the backing plate construction, not necessarily to be credited to the welding method, is less time in die set-up in the shops and less space taken in storage bins.

The process has become established, is thoroughly practicable, is in regular use, and has returned savings so far well above the expected amounts.

The writer would like to call attention particuarly to the punch shown in Fig. 6. This happened to be die No. 1. This punch is a small, three-point, star-shaped piece of tool steel with a hole in it but with no sign of a flange. This punch was successfully welded. This little piece welded to the backing plate as described, indicates great possibilities of this system as a money saver.

Chapter IX—Typical Arc Welded Jigs and Fixtures

By Ernest Kirshtner and Ernest L. Kirshtner,
Foreman and draftsman, respectively, Austin Western Road Machinery Co. Harvey, Ill.

The Western Austin Company saved over 30% in cost and time when they adopted welded jigs and fixtures for their new motor grader. In addition, they secured other benefits which are inherent in the welded design of such items as jigs, bulldozer dies, boring, welding and milling fixtures, etc. Jigs and fixtures for this machine were begun in April, 1937 and the first finished machine left the assembly line in September, 1937.

The motor grader is a rather complex machine, self-propelled, all-wheel drive and all-wheel steer, weighing 15,000 lbs. to 16,000 lbs., depending upon equipment. Accuracy in manufacture of parts was most important, not only to insure proper performance but for assembly purposes. Furthermore, seasonal and market conditions made early production important, and any time saved in tooling up would hasten production.

Tooling up for production required a total of 112 special jigs, dies, fixtures, etc. which were made at an actual cost of $8,476.24 and in a total of 3696 man-hours.

Before adopting welded design for these tools, a careful estimate was made to show the cost and the time required for cast design. This estimate included the patterns and their machining, plus the cost of the materials, but did not include the time required for getting the rough castings.

On this basis, it showed the cost of cast tools and fixtures to be $12,467.84, and the man-hours to be 5,264.

The saving in cost by using welded design was $3,991.60, and the saving in man-hours was 1,568, without including the time required to produce rough castings in the foundry. The direct saving in money, as well as in man-hours, exceeded 30% in each case.

In addition, welded design gave other advantages over cast design.

1. Price: Rolled steel does not have the wide price fluctuations of castings. Steel casting prices are especially unstable. The more constant material costs of welded design tools and fixtures is desirable.
2. Uniformity: Rolled steel is dependable and uniform as to quality. This cannot be claimed for castings, either iron or steel. Blow holes and internal strains often are present in castings, and frequently these are not discoverable until part, or all of the manufacture is finished. This hazard may add to the cost of cast tools.
3. Safety factor: The uniformity of rolled steel assures a dependable safety factor. There is little liability of failure in service, of a welded design tool. Castings are not reliable in this respect, and unsuspected blow-holes, or other weakness, may cause unsuspected breakage.

4. Weight: The certainty of getting required strength from rolled steel, permits the use of a minimum amount of metal in tools and fixtures of welded design. Cast fixtures require an excess of bulk and weight to insure proper service life.
5. Service life: Rolled steel is not subject to hidden and unsuspected weaknesses, (provided the design and workmanship are adequate) and therefore welded design tools and fixtures may be counted on for a long, dependable service life. Progressive failures in service are rare. Changes in design can easily be made by burning and rewelding.

Summary: Welded design gives advantages over cast design, such as superior physical qualities of steel; simplicity of design; ease and speed of fabrication; superior service life; and savings of cost on material and production.

Examples of Tools.—Obviously, there is no need to recite in detail, particulars on the entire 112 welded fixtures for this machine. Illustrations of all the points set forth can be shown by eight typical examples, showing types and sizes used. These examples follow:

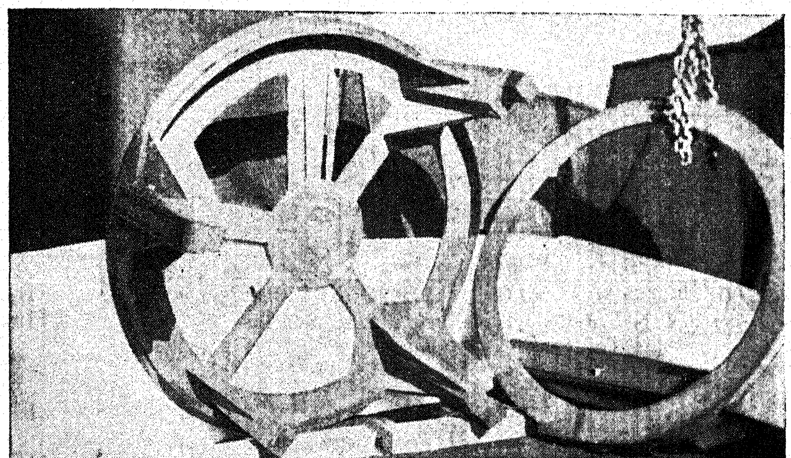


Fig. 1. Milling fixture for circle.

MILLING FIXTURE FOR CIRCLE (Fig. 1)

Welded Design—1505 Lbs.

Steel	Layout	Burning	Welding	Normalizing	Machining	Total Cost	Time
1″ plate 1355 lbs. $30.50	$1.84	$1.13	74 Ft. $44.50	$2.10	$12.74	$92.71	50 Hrs.

Cast Fixture—1808 Lbs.

Tool Design	Pattern Making	Wood	Casting	Machining	Total Cost	Time
$7.00	$67.50	$6.00	$72.00	$18.62	$171.12	64 Hrs.
	Saved by arc welding			**303 lbs.**	**$ 78.41**	**14 Hrs.**

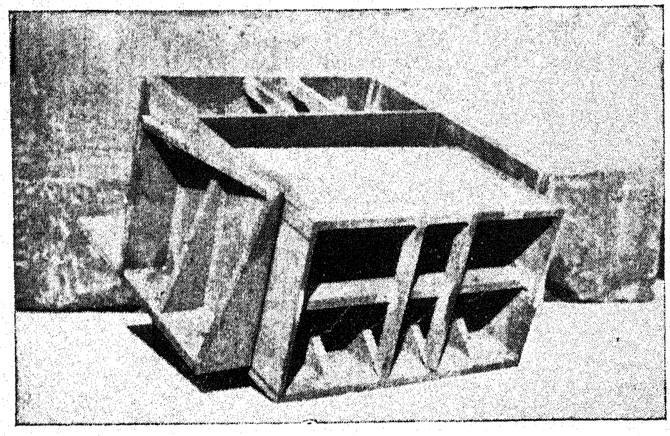


Fig. 2. Movable and stationary die.

DIE, MOVABLE AND STATIONARY (Fig. 2)

Welded Design—1634 Lbs.

Steel	Layout	Burning	Welding	Normal-izing	Mach-ining	Total Cost	Time
1″ plate 1554 lbs. $34.97	$1.61	$ .94	90 Ft. $49.50	$1.75	$14.70	$103.47	36 Hrs.

Cast Design—1980 Lbs.

Tool Design	Pattern Making	Wood	Casting	Machining	Total Cost	Time
$6.00	$52.50	$7.00	$79.20	$20.46	$165.16	57 Hrs.
	Saved by arc welding			346 lbs.	$ 62.69	21 Hrs.

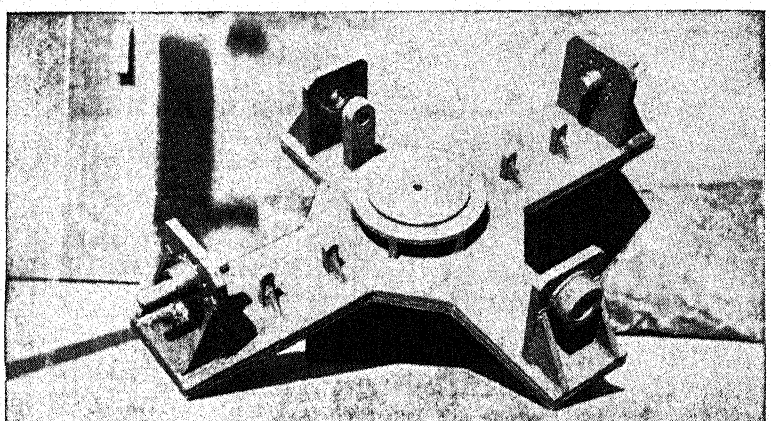


Fig. 3. Drill jig for front axle.

DRILL JIG FOR FRONT AXLE (Fig. 3)

Welded Design—792 Lbs.							
Steel	Layout	Burning	Welding	Normalizing	Machining	Total Cost	Time
1″ plate ¾″ ribs 637 lbs. $4.34	$3.80	$1.50	50 Ft. $50.00	$1.58	$12.76	$73.98	36 Hrs.

Cast Design—950 Lbs.						
Tool Design	Pattern Making	Wood	Casting	Machining	Total Cost	Time
$6.00	$37.50	$3.00	$38.00	$17.93	$102.43	43 Hrs.

Saved by arc welding................158 lbs. $ 28.45 7 Hrs.

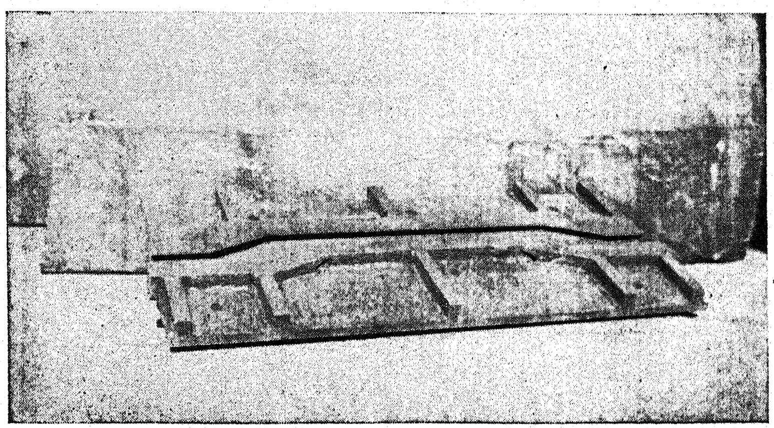


Fig. 4. Die for front steer rod.

BULLDOZER DIE FOR FRONT STEER ROD (Fig. 4)

Welded Design—228 Lbs.							
Steel	Layout	Burning	Welding	Normalizing	Machining	Total Cost	Time
1″ plate 1½″ ribs 156 lbs. $3.51	$1.75	$1.00	28 Ft. $45.00	$1.50	$14.90	$67.66	26 Hrs.

Cast Design—273 Lbs.						
Tool Design	Pattern Making	Wood	Casting	Machining	Total Cost	Time
$6.00	$52.50	$6.00	$11.00	$16.66	$92.16	58 Hrs.

Saved by arc welding.................45 lbs. $24.50 32 Hrs.

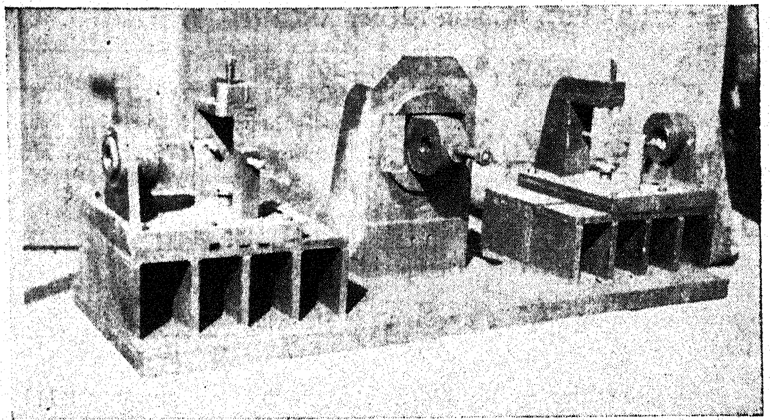


Fig. 5. Boring fixture for front axle.

BORING FIXTURE FOR FRONT AXLE (Fig. 5)

Welded Design—2068 Lbs.

Steel	Layout	Burning	Welding	Normalizing	Machining	Total Cost	Time
1″ plate 1933 lbs. $43.50	$3.22	$2.25	140 Ft. $77.00	$1.70	$36.25	$163.92	63 Hrs.

Cast Design—2512 Lbs.

Tool Design	Pattern Making	Wood	Casting	Machining	Total Cost	Time
$6.00	$67.50	$6.50	$104.50	$43.12	$227.62	95 Hrs.
	Saved by arc welding			**444 lbs.**	**$ 63.70**	**32 Hrs.**

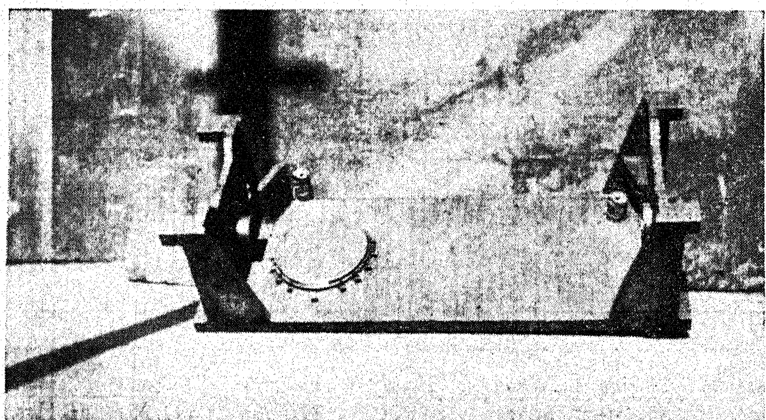


Fig. 6. Drilling fixture for axle.

DRILLING FIXTURE FOR AXLE (Fig. 6)

Welded Design—848 Lbs.

Steel	Layout	Burning	Welding	Normalizing	Machining	Total Cost	Time
1″ plate 1″ Sq. ribs 658 lbs. $14.81	$1.84	$1.10	95 Ft. $52.00	$ .70	$9.80	$80.25	33 Hrs.

Cast Design—1000 Lbs.

Tool Design	Pattern Making	Wood	Casting	Machining	Total Cost	Time
$6.00	$28.00	$4.00	$41.00	$11.76	$90.76	34 Hrs.
	Saved by arc welding...............			152 lbs.	$ 9.51	1 Hr.

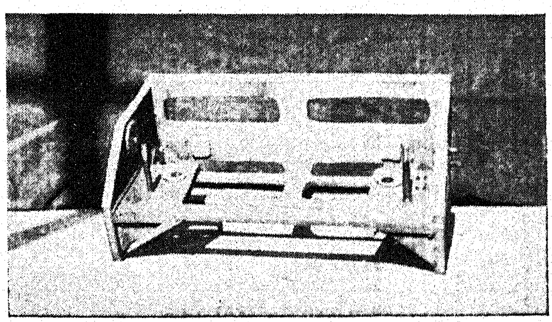


Fig. 7. Drill jig for frame tie.

DRILL JIG FOR FRAME TIE (Fig. 7)

Welded Design—362 Lbs.

Steel	Layout	Burning	Welding	Normalizing	Machining	Total Cost	Time
1″ plate 307 lbs. $6.91	$1.84	$1.10	30 Ft. $18.00	$1.00	$12.74	$41.59	25 Hrs.

Cast Design—434 Lbs.

Tool Design	Pattern Making	Wood	Casting	Machining	Total Cost	Time
$4.00	$30.50	$2.00	$18.00	$10.62	$65.12	39 Hrs.
	Saved by arc welding...............			72 lbs.	$23.53	14 Hrs.

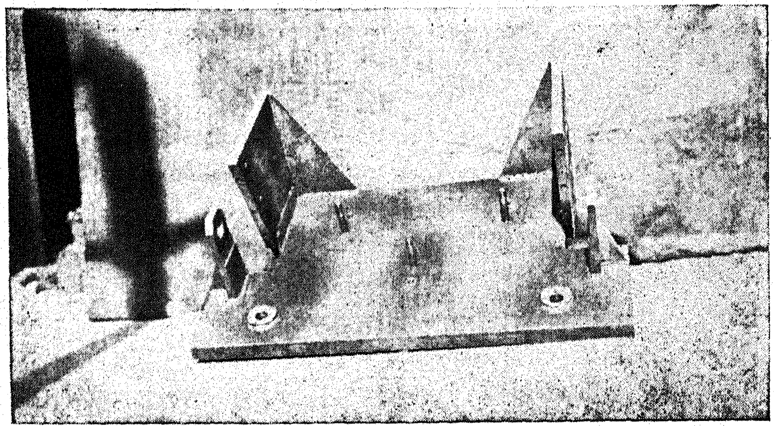


Fig. 8. Drill jig for center plate.

DRILL JIG FOR CENTER PLATE (Fig. 8)

Welded Design—575 Lbs.

Steel	Layout	Burning	Welding	Normalizing	Machining	Total Cost	Time
1″ plate 1″ Sq. ribs 480 lbs. $10.80	$1.84	$1.10	45 Ft. $27.00	$1.00	$17.64	$59.38	32 Hrs.

Cast Design—690 Lbs.

Tool Design	Pattern Making	Wood	Casting	Machining	Total Cost	Time
$4.00	$30.00	$3.00	$29.00	$21.56	$87.56	46 Hrs.
Saved by arc welding..............				115 lbs.	$28.18	14 Hrs.

All the steel used is S.A.E.-1020-H.R.S. with the size of welds varying from ½″ single pass to ¾″ double pass fillets.

The cost of tool design has been eliminated on these welded fixtures, because they all were developed in the welding shop by use of th production drawing only.

Normalizing is an important step that governs the entire life and service of a welded design with rigid and fixed joints, or a design that has close machining tolerance that are subjected to dynamic service loads. All of our fixtures have been normalized at 1550° to relieve any possible development of such internal strains which may impair the service life of the structure.

The development of these welded fixtures with its outstanding 30% savings of time and money shows the value of this ever increasing and expanding industry.

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